CENTRAL HIMALAYA

GEOLOGICAL OBSERVATIONS
OF THE SWISS EXPEDITION 1936

by

ARNOLD HEIM

and

AUGUST GANSSER

With 162 text figures and an atlas containing geological maps
with a generalized section in colours,
5 plates of detailed sections,
18 plates with 65 photo-views and 3 plates with 21 micro-photographs

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TO THE MEMORY

OF

ALBERT HEIM

FOREWORD

The publication in 1939 of the monumental memoir by Arnold Heim and August Gansser on the geology of one of the most crucial and responsive regions of the Himalaya opened the geologically little-known Kumaun to the world. Immensely informative, tremendously stimulating and profusely illustrated, this comprehensive memoir by two highly experienced and ardently dedicated mountain geologists has served as a valuable supplement to the works of C. L. Griesbach on the Tethys Himalaya to the north, of D. N. Wadia on Kashmir, of G. E. Pilgrim, W. D. West and J. B. Auden on Himachal Pradesh to the west. The observations, interpretation and conclusions of Heim and Gansser have widely and profoundly influenced the philosophy of thinking and the styles of working of Himalayan geologists and the volume has served as an indispensable guide and reference work to all enquiring workers that followed them in Kumaun and adjoining regions.

Much work has been done in Kumaun since the publication of this memoir, but most of the later investigations, carried out preponderantly by the academic institutions, are of the nature of isolated, localized spot-studies, with greater emphasis on restricted fields of specialization such as analysis of mesoscopic structures, petrography and petrogenesis of granitic and associated metamorphic rocks, etc. Regional studies of the kind Heim and Gansser undertook have, however, been done in eastern Kumaun and in parts of Garhwal. These investigations have by and large established the validity of the premises of Heim and Gansser and amply confirmed their tectonic deductions. In the field of stratigraphic order and correlation, especially in the Lesser Himalaya, there have been modifications and changes.

Following the trails of Heim and Gansser I have myself traversed quite a part of the Kumaun Himalaya and extended the area of study westward upto the River Tons that forms the frontier of Himachal and Kumaun. My studies, and the studies of a host of recent workers, have amply confirmed the existence of various thrusts demonstrated and postulated by Heim and Gansser, although there are disputes regarding the attitude, nature and delineation of a few of them. Below the overthrust 'Central Cryssallines' of the Great Himalaya the sedimentary formations in the Chamoli and Almora districts are split up into a number of tectonic scales giving rise to zones of schuppen. The Main Central Thrust, regarded by Heim and Gansser as the great plane separating the Great Himalaya from the Lesser Himalayan domain, seems to be but the largest and most persistent thrust of the schuppen zones; the real boundary between the two domains being quite to the north of the Main Central Thrust. Recent investigations have futher demonstrated existence

of yet another tremendous regional rupture, the Malari fault, demarcating the northern boundary of the Great Himalaya. Between these two thrusts the lofty Great Himalaya seems to rise as a colossal tectonic slab, which is probably still active. Detailed mapping and structural studies have conclusively established the North Almora Thrust as a great tectonic feature separating the Lesser Himalaya into two distinctive lithotectonic realms. The position of the South Almora Thrust is, however, disputable. It is found that the thrust which passes through the vicinities of Dhaun, Mukteshwar, Suwalbari, Uprari and Bhikiasen is the real South Almora Thrust representing the southern flank of the North Almora Thrust. There is yet another thrust, called the Ladhiya Thrust in southeastern Kumaun or the Ramgarh Thrust in central part, which defines the base of the tectonic unit made up of low-grade metasedimentaries and strongly sheared and mylonitized porphyritic granite and quarzt-porphyry. This lithotectonic unit thus lies imbricatedly under the Almora nappe. Recent studies have shown considerable structural complexities in the proximity of the thrusts, such as imbrication, inversion of beds resulting from overturning and recumbent folding or thrust faulting, and the like, leading to conflicting interpretations and controversies. A large number of transverse tear faults, some of which extending tens of kilometres, have been discovered, largely from the interpretation of aerial photographs and very detailed and deep studies in connection with construction of dams. Likewise, high degree of seismicity, with distinctive pattern of distribution of epicentres in northeastern Kumaun, has been interpreted as suggestive of neotectonic movements taking place along these faults. Interestingly, these tear faults evince parallelism with the transverse fractures and faults discovered by aeromagnetic surveys in the basement of the Ganga Basin.

In the stratigraphic field, significant advances have been made, necessitating revision of the schemes of stratigraphic order and correlation. In the outer sedimentary belt of the Lesser Himalaya the Infrakrol rocks, near Nainital, have yielded spores and pollens suggesting Permo-Traissic age, while in the Nadhaur valley to the southeast the same formation contains bryozoans of Middle Palaeozoic age. The Tal that succeeds the Krol in Pauri-Garhwal has recently revealed Permian brachiopods, fusulinids, bryozoans and calcareous algae, although some workers, who regard the Tal as Jurassic-Cretaceous in age, believe that these Permian fossil-bearing soft sediments have been brought there from the far north by thrusting. In the inner sedimentary belt identifiable forms of profusely and widely developed stromatolites in the carbonate rocks of the Tejam-Badolisera calc zones (which I call the Gangolihat Dolomite) indicate Upper/Middle Riphean (Purana) age. Heim

and Gansser had equated them with the Krol of, what is commonly believed, early Mesozoic age. The sericitic and often pebbly orthoquartzites with invariably associated basic metavolcanics—my Berinag Formation—have been found to be pronouncedly thrust over the carbonate rocks in many a locality. The Berinag appears to be the equivalent of the Nagthat Formation of the outer sedimentary belt. Below the Gangolihat Formation lies the protean formation of Rautgara, consisting of muddy quartzites alternating with slates, subordinate conglomerates and a sizeable volume of basic intrusives. And between the Gangolihat and the Berinag there is an impersistent horizon —the Sor—of carbonaceous-pyritic slates alternating with marble. Thus, four distinctive lithological units have now been clearly recognized in the inner sedimentary belt of the Lesser Himalaya.

In the Tethys Himalaya the Upper Garbyang of Heim and Gansser has revealed a Middle Ordovician fossil, and the discovery of fossiliferous Lower and Middle Carboniferous below the Middle Permian horizon has considerably lessened the span of the Hercynian gap postulated by these workers.

Kumaun is being extensively investigated for minerals, especially base metals and radioactive minerals. These investigations are yet to prove fruitful. However, what Heim and Gansser had described as pockts of barite in the dolomite have turned out to be lentiform deposits of coarsely crystalline spathic magnesite of great economic potential. Together with the associated talc, the magnesite is being commercially mined on a large scale.

To the east in Nepal there has been an upsurge of vigorous investigation by a number of parties. They have come out with dismayingly divergent interpretations and conclusions, thus vastly complicating the picture of the tectonic architecture and stratigraphic setting. Even as new lines of enquiry and increasing efforts in research have led to unveiling of a wealth of significant facts, forests of baffling question marks have grown side by side. Sharply conflicting interpretations and disconcertingly divergent conclusions by recent workers in Nepal, Kumaun and Himachal have again brought home the indispensability of this memoir by Heim and Gansser, portraying the Kumaun Himalaya as an epitome. Perusal of this work is thus an essential prerequisite of all researches in the Himalayan Geology. Consequently, the demand for the rare work—gone out of print for a long time—has been very keenly felt by researchers and professional workers alike. All Himalayan earth-scientists would be very grateful to Professor A. Gansser for permitting the Hindustan Publishing Corporation to reprint the memoir and making it available once again to the geological community.

K. S. VALDIYA

Atlas, containing:
Geological map in colours, with general section
5 plates of sections
21 plates of photographs

PREFACE

After having devoted about twenty years to the geological study of the Alps, especially to the problems of thrusting and their relation to facies-stratigraphy, I had the opportunity to traverse the great Asiatic mountain systems: the Yangtse region and Chinese Tibet in 1929—1931, and the meridian ranges of Further India (north-western Siam) in 1935: Finally, in 1936, my long-cherished hope to make a comparative study of the Himalaya—the highest and youngest mountain range of our globe—was realized.

My plan of a small Swiss expedition was taken up and made possible by the generous support of our Swiss Academy, the "Schweizerische Naturforschende Gesellschaft".

From the tectonical point of view, the Central division of the great Himalayan Range seemed to present the greatest interest. Indeed, most of the former expeditions have chosen either the south-eastern divisions, departing from Darjeeling to Kangchenjunga or Mount Everest, or the regions to the north-west in Kashmir and the Karakorum. The Kingdom of Nepal, with the highest mountains and the deepest transverse gorges of our globe, being closed to foreigners, it was the British Province of Kumaon, on its north-western side, which we selected as the main sphere of our activity. As a matter of fact we did penetrate also into the forbidden territories of Nepal and as far as the Transhimalaya in Tibet, since those regions were likely to yield the most important geological results (see map).

For the purpose of preliminary studies we first visited the surroundings of Darjeeling, on the south-eastern side of Nepal. Then we proceeded 750 miles further to the NW, as far as Tehri Garhwal and Mussoorie. We were able to make the latter excursion thanks to the invitation of our colleague, Mr. J. B. AUDEN of the Geological Survey of India, who was entrusted with the mapping of the region between Solon and Lansdowne. It is to him that we owe our knowledge of the formations and the structure of those border ranges. Whenever we had occasion to come into contact with the Geological Survey of India at Calcutta — either by personal call or by correspondence—the greatest kindness was shown to us and we were given every possible help.

Our expedition was limited to three members, as it was thought that a small group of tourists would not only be cheaper, but also relatively more efficient than a large one.

Our thanks are due to the experienced Alpinist WERNER WECKERT of Zurich who arranged and sent out to India the complete outfit for camping including part of the provisions. Should we, at some future time, embark upon another expedition, we would take fewer provisions with us, as the essential foodstuffs, such as wheat, barley and potatoes, are usually ready for sale even in the highest villages of the Central Himalaya. According to our experience, this simple vegetarian "food of the coolies" is not only very cheap, but much healthier than the stodgy canned and sometimes poisonous foodstuffs.

At the end of April, when everything had arrived at Almora and the long march towards the snow mountains had begun, a great disaster overtook us: Mr. WECKERT fell ill and had to be carried back to a hospital for an urgent operation of appendicitis. He was most unfortunately unable to join us again, and we were reduced to two—too small a number for safe travelling and high climbing. If in spite of this we managed to traverse and study a larger region than had been anticipated—and that during the worst monsoon season known to the mountain people—

it is thanks to my young colleague, Dr. AUGUST GANSSER, of Lugano. He was not only an excellent companion on our eight months travellings, but proved to be of extraordinary scientific aptitude, an indefatigable worker and a first class Alpinist. After having published some preliminary reports[1], we brought out together our book "Thron der Götter"[2] which appeared in November 1937. It gives a complete account of our experiences and adventures. Furnished with a new relief map in natural light (from SW), it is a contribution towards the geography of the Central Himalaya and further on to the Transhimalaya. giving particulars regarding the people, the plants and animals as well as the gorges, glaciers, plateaux and summits. As far as possible we have made it a book for the general reader. It has a final chapter on our general geological results, however without geological maps and sections.

The present volume, on the other hand, is a purely geological publication, its main object being to elucidate the Himalayan structure. All designs, and the photographs with one exception, have been made by the authors (H = HEIM, G = GANSSER). The map 1 : 650000 has been worked out by the well-known firm of KÜMMERLY and FREY in Berne, whom we have to thank for their help.

Considering that the greater part of the Himalaya and its literature are English, and that practically all geologists interested in the Himalaya are reading English, this language was chosen. While the text of H was written directly in English, that of G was translated by H from the German.

Professor Dr. P. NIGGLI, on his part, has examined through the microscope some of our 370 slides of Himalayan rocks.

Dr. W. LEUPOLD of Berne has kindly made and examined some of our sedimentary slides.

To Professor Dr. C. BURRI of Zurich we are greatly indebted for his help in determining the feldspars, and for writing the special chapter on the volcanic pebbles of the Kailas included in the present text.

Professor Dr. J. JAKOB, our authority on silicate chemistry, has greatly helped us in making 10 complete rock analyses.

The most important contribution we owe to our friend Professor Dr. A. JEANNET of Zurich. With unfailing energy he has studied our fossil collections. Practically all the determinations mentioned in this book are due to him. His complete paleontological research will be published in a Memoir of the Geological Survey of India.

Our collections have been presented to the Geological Department of the Swiss Federal Institute of Technology (S. F. I. T.) of Zürich.

Dr. A. GANSSER, assistant of this geological Institute, after having been granted leave for our expedition, enjoyed his position again for working out this publication. For this purpose, the head of the geological department, Professor Dr. R. STAUB, kindly provided us with a special room.

The S. N. G. (Swiss Academy of Sciences) has not only generously assisted our expedition, but its Committee for Reports put its whole means available during the current year at the service of the present publication.

Nevertheless, these means would not have been in any case sufficient to cover the heavy costs for printing and illustrating if there had not been large subsidies from many quarters.

We are especially indebted for large contributions from the Central Fund of the S.N.G. through the good offices of the Central Committee and its President, Professor Dr. G. SENN.

[1] ARNOLD HEIM: Die Schweizerische Himalaya Exped. 1936. Zeitschr. d. Ges. f. Erdkunde, Berlin. April 1937.
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[2] ARNOLD HEIM and AUGUST GANSSER: Thron der Götter, with relief-map, 1 : 650.000, 220 phot., 2 plates of panoramas. 18 text fig. Morgartenverlag, Zürich 1937.

Furthermore, thanks are due to the Albert Barth Fund of the Swiss Federal Institute of Technology through the kind efforts of Professor Dr. A. ROHN, President of the Swiss School Council, and to the Foundation Dr. Joachim de Giacomi of the S. N. G. (President Dr. R. LA NICCA). For further contributions towards the expenses of the publication, we are indebted to the Central Committee of the Swiss Alpine Club (S. A. C.), to the Swiss Re-Insurance Society and to its President, Dr. CH. SIMON of Zürich; to the Swiss Society of Insurance against Accidents at Winterthur, and to Dr. C. J. ABEGG of Zurich.

Our thanks are further due to the following persons or firms in Switzerland for having financially supported our expedition:

Mr. IWAN BALLY, Schönenwerd,
Mr. A. DÜRLER-TOBLER, Engineer, and HANS TOBLER, Zurich,
Dr. A. WANDER, Berne, through Director SCHAFFNER,
Grands Magasins JELMOLI, Zurich,
Mr. PAUL MONTANDON, Thun.

We also remember thankfully the numerous firms in Switzerland mentioned in our general book "Thron der Götter", who have furnished us with mountaineering outfit and provisions.

To the editor, Professor Dr. E. LUDWIG of Basle, who has put in all his care and energy to bring this work to a satisfactory end, the authors are very grateful.

Zurich, February 1938 ARNOLD HEIM

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INTRODUCTION

Geographical Features

Forming an enormous arch, the Himalayan border is bent towards the great Indian plain, over a length of 1500 miles (2400 km.) This fact in itself suggests a general movement of the Himalayan Ranges towards the south and south-west. The southern border of this arch is much more clearly defined than the corresponding northern border of the smaller Alpine arch. It commences with the Siwalik-Tertiaries in the east at Nizamghat (north of Sadiya) and reaches in the north-west the Jhelum River of the Punjab (Wadia). At both of these extremities the front ranges suddenly turn towards the south, apparently around the edges of the old Gondwana block. (Fig. 1) There, in a nearly symmetrical way, the two great rivers, the Indus and the Brahmaputra (= Tsangpo) have found their outlets across and around the Himalayan arch. Both originate in the Tibetan Highland, behind the central part of the Himalayan Ranges, in the Transhimalayan region of the holy Kailas. These two main rivers thus embrace the whole Himalaya. The Sutlej originates on the big plateau of the Manasarovar and Raksas Lakes in Tibet, at an altitude of 4500—4600 meters, and after having crossed the Himalayan Ranges near Simla, it flows into the Indus. The Ganges with its tributaries originates in the northern Himalayan Ranges and after leaving the mountains turns towards the south-east, where it joins the Brahmaputra.

Geographically, and geologically in part, the ranges of the Central Himalaya (Kumaon) and northward to the Transhimalaya (Tibet) are subdivided as follows, from south-west:

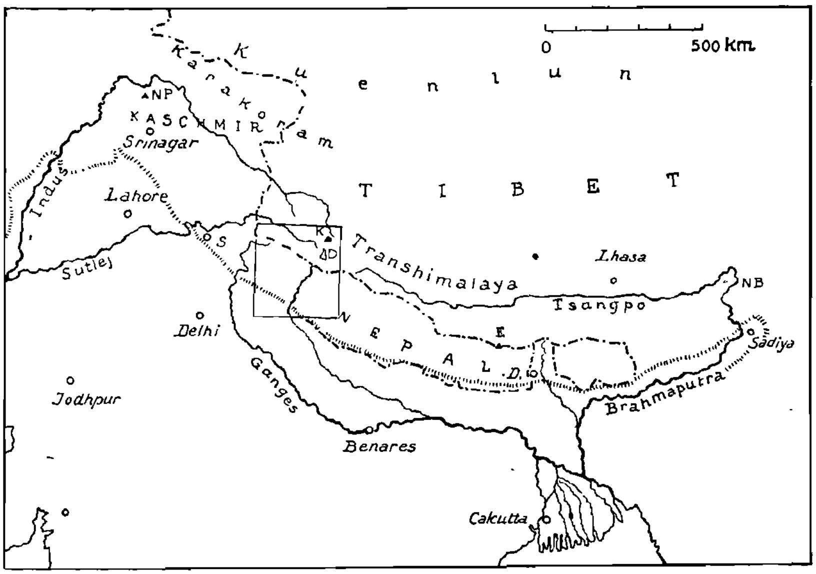

Fig. 1. Index-map of the Himalaya. The square on the NW side of Nepal corresponds to the geological map 1 : 650,000 of this book.

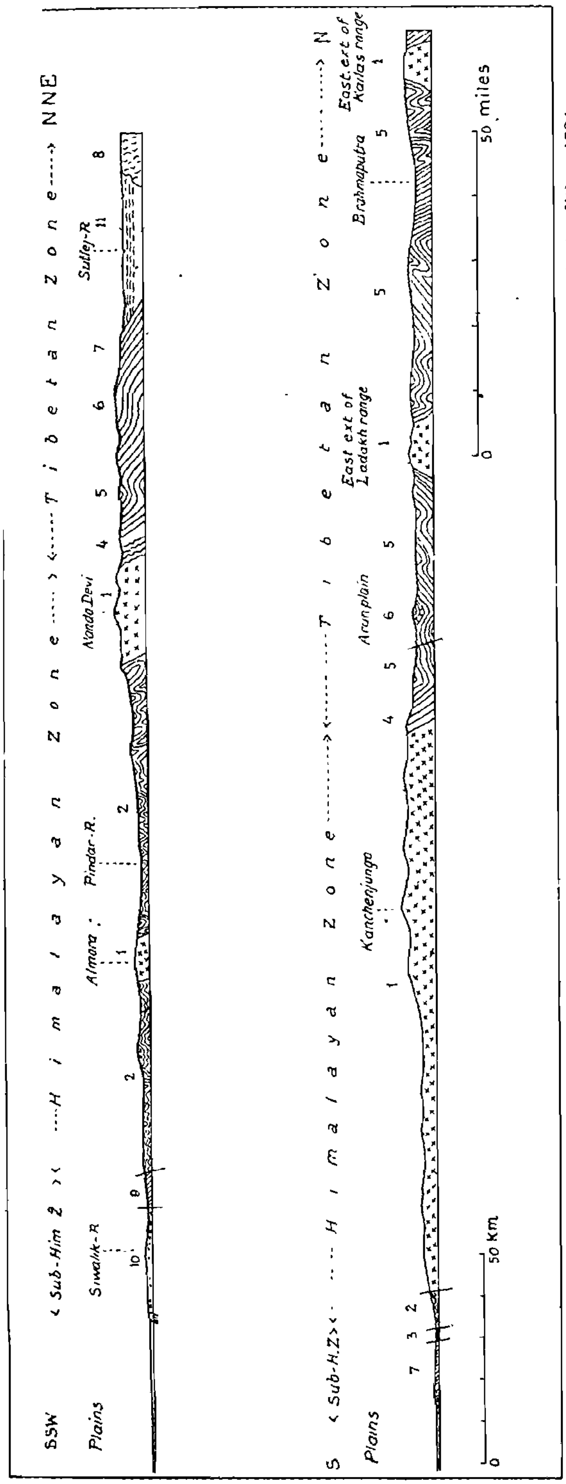

Fig. 2. "Diagrammatic Sections across the Himalaya' after BURRARD and HAYDEN'S "Geology of the Himalaya", revised edition 1934.

1. Subhimalaya (Border Zone) or Siwaliks (Tertiary) width 5-10 km.
2. Lower Himalaya (Outer Himalaya, unfossiliferous) „ 70-120 km.
3. High Himalaya „ 40-65 km.
   a) Central High Range (Nampa - Nanda - Devi - Badrinath) „ 15-30 km.
   b) Northern Ranges or Tethys-Himalaya (AUDEN), the Tibetan Border Range or Zaskar Range incl., marine, fossiliferous „ 20-35 km.
4. Hundes Highland, Tibet „ 70-80 km.
5. Transhimalaya (Kailas Range) „ 40-60 km.

Former Geological Investigations

An excellent general account of our knowledge of Himalayan geology is presented in the official book "The Geology of the Himalaya", revised edition of 1934. This standard work not only gives information about the great work done by the Geological Survey of India, but also contains important reproductions of sections and special maps, while the new general geological map 1:3.168.000, although not altogether accurate, gives a general view of almost everything that has been mapped so far. Not only Bhutan and Nepal, but also the greater part of Kumaon is left in blank, while a great part of the northwestern Himalaya, beyond the Sutlej, has already been mapped.

With regard to the structural conceptions, the sections published in "Geology of the Himalaya" are somewhat contradictory. The general sections of pl. XXXVIII (reproduced in our Fig. 2) with their gentle autochthonous folding and a nearly vertical "main boundary fault" recall a period about half a century ago. Other plates, on the contrary, are based

on recent mapping in the north-western border region and present the modern conception of thrusting. (PILGRIM, WADIA, WEST, AUDEN).[1]

The author of the oldest publication on the Central Himalaya and the only one issued with a geological sketch-map covering a great part of the region of our research is Captain RICHARD STRACHEY. He already traversed the Central Himalaya in 1848–49, and published his paper "On the Geology of part of the Himalaya Mountains and Tibet" in 1851 (59). His sections (Fig. 3) on a natural scale, although not showing any thrusting are a remarkable achievement for that time. Indeed, STRACHEY already clearly distinguished the main stratigraphical divisions of the High Himalaya, from the "azoic slates", the Silurian which was determined after his fossil collections, up to the secondary formations, all dipping towards north-east.

It seems that R. D. OLDHAM in 1893 was the first investigator realizing the general thrusting movements of the Himalayan Ranges over the subsiding Indian Plain. Highly important results bearing on the question of the young age of the whole Himalaya have recently been obtained by WADIA, SAHNI and DE TERRA in Kashmir and Karakorum.

The first modern section of thrustfolding over the entire width of the Himalaya, although done in a schematic way, was presented by a foreigner, not mentioned in "The Geology of the Himalaya". It was the Hungarian professor L. v. LÓCZY, who, after having rapidly traversed the eastern Himalaya as early as 1878, published his remarkable "Beobachtungen" in 1907. His sections of Kangchenjunga (Fig. 4) showing an enormous overfold with huge reversed series thrust for 150—200 kilometers towards the Indian Plain are more correct in principle than the later essays by DYHRENFURTH in 1932 and WAGER in 1933. They are confirmed by AUDEN's "Traverses" (4) and by our own observations.

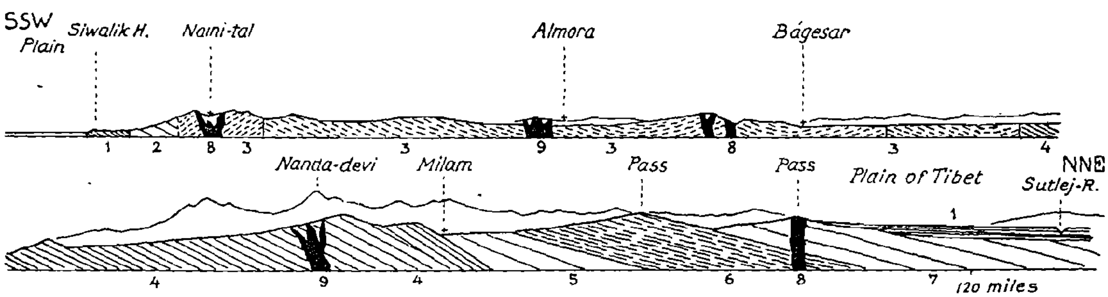

Fig. 3. The first section across Central Himalaya by Captain RICHARD STRACHEY. Quarterly Journ. 1851.

1 = Tertiary	4 = Crystalline schists	7 = Secondary
2 = Secondary and Paleozoic??	5 = Azoic slates	8 = Greenstone
3 = Metamorphic strata without fossils	6 = Palaeozoic	9 = Granite

(Numbers not figured in the original.)

While the unfossiliferous border ranges of the north-western Himalaya, north-west of the Ganges, are being systematically mapped in detail by the excellent geologists of the Geological Survey of India, little or no work had been done for a long time in the interior Himalayan

[1] The former director of the Geological Survey of India, Sir LEIGH FERMOR, in a discussion with the writer, expressed the opinion that systematic mapping was the only way to advance our structural knowledge of the Himalayas. Had systematic mapping been applied exclusively in the Alps, the prolific conception of thrusting, however, might have been delayed for half a century. The reader may judge for himself whether the rapid excursions of the authors through the Central Himalaya were scientifically justified.

Ranges. There, the great pioneer work was done at the end of the last century. Thus H. H. HAYDEN's survey of the region of Spiti, north-east of Simla, with its rich fossiliferous horizons has become of primary value, while GRIESBACH in 1891 mapped its south-eastern continuation in north-eastern Kumaon. His sections designed with much natural skill have been found however to need ample correction.

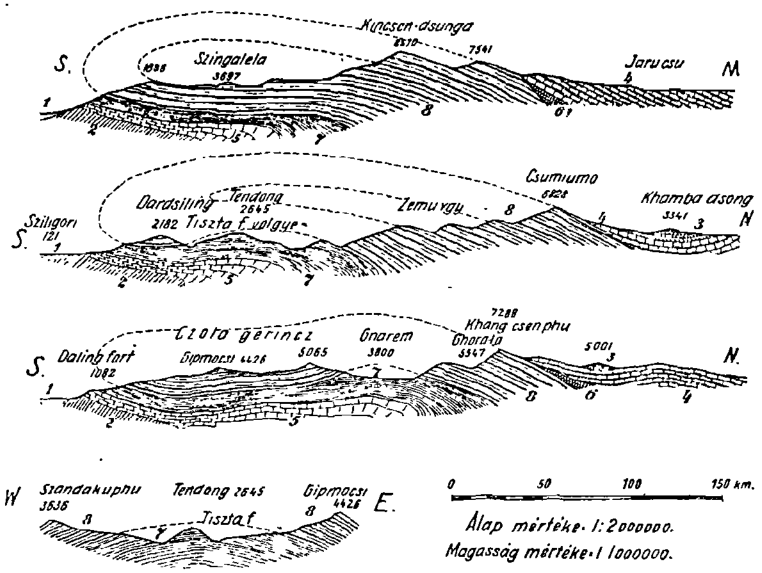

Fig. 4.
Tectonical section of Kangchendjunga-Darjeeling by L. v. LÓCZY, 1907.

In the Tibetan border range of northern Kumaon, C. DIENER and GRIESBACH discovered the famous "exotic blocks", which some years later were carefully studied by A. VON KRAFFT. Although DIENER had compared them with the "Klippen" of the Alps, VON KRAFFT concluded that they originated from huge volcanic outbursts on the Tibetan side which he was forbidden to traverse. ED. SUESS, after VON KRAFFT's description[1], concluded, however, that the phenomena were related to great overthrusts.

Within the region which we traversed in Kumaon, in north-western Nepal and Tibet, only the southern border ranges as far as Nainital, and the Tibetan border ranges had been mapped, the intervening part being shown blank. It is true that on the geological map of the Himalaya 1:3.168.000 the surroundings of the great Lake Manasarovar too are coloured, although no geologist before us seems ever to have studied that Tibetan region; the mapping is accordingly misleading.

Bhutan and Nepal excepted, which are practically unknown, the tectonical conception of the Himalaya at present is about in the stage of that of the Alps in 1902 when the theory of thrusting became victorious.

[1] VON KRAFFT's mapping is not reproduced in the Geological map of the Himalaya by BURRARD and HAYDEN in 1934.

THE SIWALIK BORDER REGION

The Border Section of the Tista River, Bengal

Similarly to the discoveries in the Alps at the beginning of this century, the younger generation of the geologists of India have recognized that the so-called "main boundary fault" (Fig. 2) at the interior contact of the Siwaliks is a thrust plane, the older Himalayan formations overriding the Tertiaries of the border zone. The question to our mind was to find out the true nature of this thrust plane, no special studies of the kind having apparently been made. Wherever an abnormal contact was found, the older authors have drawn a fault line on maps and sections. We cannot, therefore, refer to them as a reliable source, and new investigations are necessary.

My first aim was to see the transverse section of the Tista river, with the aid of MALLET's careful map of 1875.

Similar to the views of last century regarding the northern border of the Alps of Switzerland (C. BURCKHARDT 1891), the Siwaliks on the Himalayan border have even recently been regarded as being overturned.[1]

Our observations made in 1935 and 1936, the results of which are shown in Fig. 5, demonstrate that the main sequence is normal.

The following four subdivisions were found, from below (south):

a) a blue nodular marl and clay with soft micaceous sandstone layers, at Sivok, about 50 meters exposed above the river, passing into

b) 1700 meters of chiefly gray sandstone interbedded with subordinate marly layers,[2] passing upward into

c) 300—400 meters of sandstone with conglomerate layers containing quartz pebbles,

d) disconnected with the normal series a—c, on the river bank north of the mile stone 16, lies an extraordinary exposure of steeply upraised and squeezed sandstone with two dark argillaceous layers and a coal seam of 2 meters with clay at the base (Fig. 5).

[1] G. O. DYHRENFURTH, Himalaya 1930, plate after p. 296, and L. R. WAGER, A review of the geology and some new observations, in H. RUTTLEDGE, Everest 1933, London.

[2] Several coal seams are exposed in this division along the Darjeeling road below Tindharia.

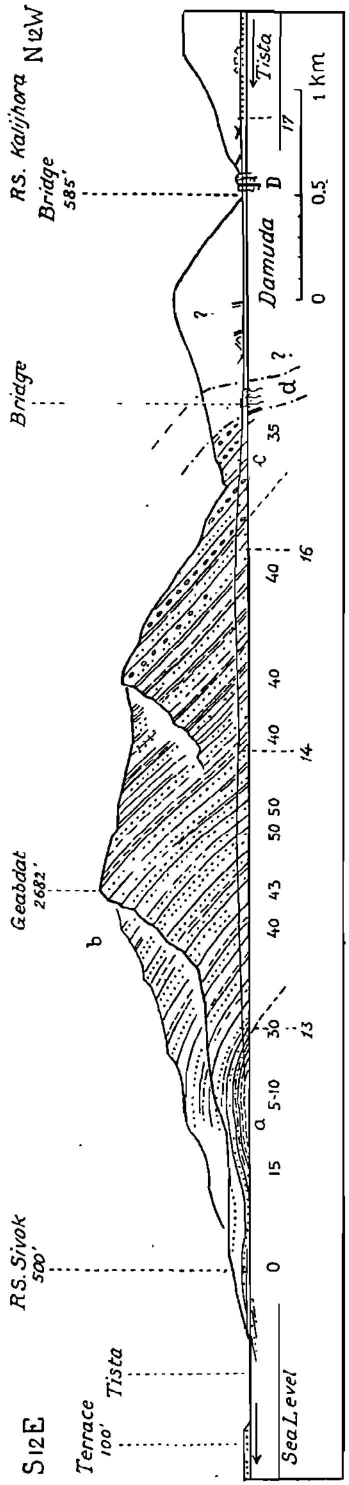

Fig. 5. The transverse section of the Siwaliks on the Tista river. a—d see text. D = Damuda sandstone with a basic sill and coal seams, upper Carboniferous. The numbers below the Tista level are degrees of dip.

The question considered at the place was, whether this interior series (d) of about 90 m visible thickness represents an erected Tertiary thrust scale pushed against the normal sequence of c, analogous to similar scales of Oligocene on the Alpine border, or whether it might be Carboniferous in spite of the softness of the sandstone.

The big mass of Siwaliks a—c, of about 2100 meters thickness is not only in a normal position, but forms a wide anticlinal arch with its apex at Sivok station, the southern limb being for the greater part removed by recent erosion and covered by alluvial deposits.

A similar anticline has been found by AUDEN (4, p. 144) in south-east Nepal (Pl. 1), where two series are present, the inner one being thrust upon the anticlinal outer one. A further analogous case is that one north-west of the Ganges as already mapped by MEDLICOTT in 1864.

The Gaps of the Siwaliks East of the Tista

Already in 1874, MALLET made the following fine observations, illustrated by strikes and dips on his map:

"The Tertiaries are wanting for some miles eastward of the Lehti naddi; they occur again in the Ma-chu, but are again absent for forty miles eastward of the Jaldoka. Their absence along this part of the lower hills... is the only instance of the kind from the Indus to the Brama Khund"... "The older formations do certainly stretch further south here, owing mainly to a change of strike, and it is possible that they originally ran still further south as a promontory in the Tertiary basin of deposition."

This position, largely based on MALLET, is shown in Fig. 6.

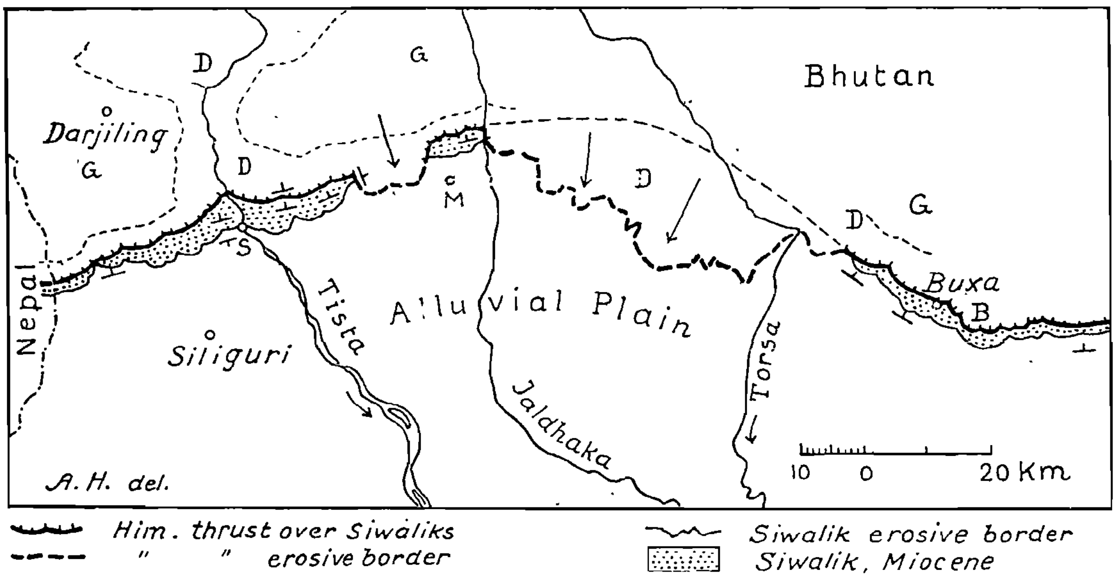

Fig. 6. Sketch-map of the Himalayan advances through the Siwalik gaps east of the Tista. g = gneiss; D = Daling series; in the western part including Damudas (Carboniferous); B = Baxa series; S = Sivok railway station; M = Matiali.

In the first of the two places mentioned by MALLET, the Siwalik front range, without changing its regular ENE direction and dip towards the mountains, ends abruptly, whereas the old Daling slates bend with a perpendicular strike around the corner in order to protrude towards the plane. Indeed on the Murti river (Ma-chu), we found the Siwaliks with conglomerate again

in the unchanged tectonical position (ENE strike), overlain by the thrust Dalings as shown in MALLET's map. Thus, the Himalayan thrust has flooded 5 kilometers towards the plain through a 15 kilometers gap in the Siwaliks.

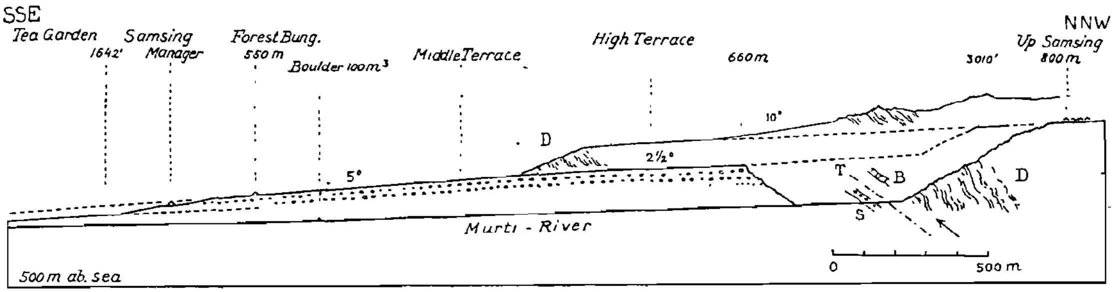

Fig. 7. The entrance of the Murti River to the plain. D = Daling series (sericite-phyllites), B = Baxa series, S = Upper Siwaliks (granite-conglomerate), T = Main boundary thrust.

The second gap is by far much larger, and equals that of western Switzerland. According to MALLET it extends from the Jaldhaka river eastward to the Kalijhora creek, on a distance of 60 kilometers, the advance of the Himalayan thrust towards the plain being as much as 20 kilometers (Fig. 6). Again, according to MALLET's map, the Siwaliks do not bend around this huge protrusion.

The view I enjoyed from the Forest Bungalow of Samsing, north of Matiali in the Duars, was an inspiration. In the form of a huge arch, the wooded Himalayan mountains project far east and south-east, one silhouette appearing behind the other, finally ending like a peninsular cape in the great alluvial plain (Fig. 8).

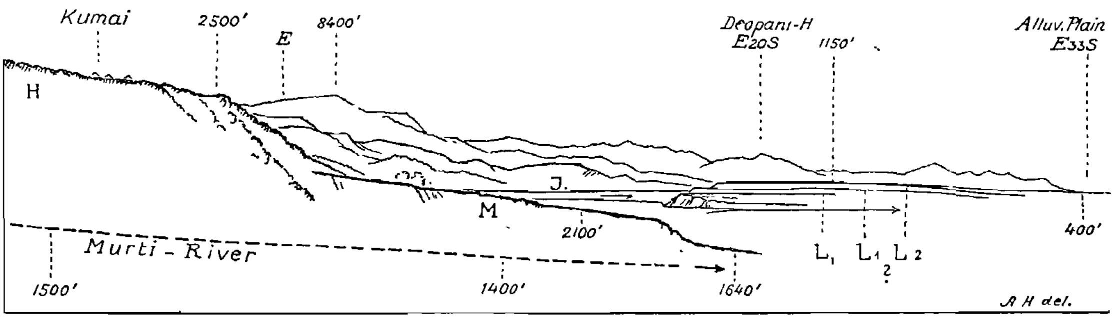

Fig. 8. Sketch-view from the Forest Bungalow of Samsing over the Himalayan Border. H high-, M middle-, L lower gravel terraces. J = Jaldhaka River.

The Quaternary Terraces East of the Tista

The northern border of the Indian plain along the Himalayan foot-hills east of the Tista and especially in the surroundings of Matiali (railway terminus) would be an "El Dorado" for the morphologist able to spend some weeks there. Our rapid visit, in April 1936, resulted in the following observations:

Coming from Siliguri to the mountain border, the alluvial plain rises very gently, then gradually more rapidly. East of the Tista, however, very gentle hills of gravel rise out of the plain, in a parallel line to the Siwaliks at 6—8 miles distance to the south of the mountain border, in the shape of a foreland-anticline in its first stage of erection. At Chalsa railway station,

the terraced hills rise to even 300 feet above the bottom of the valley. Five terraces, all in gravel, are traced on the hill one mile west of the station (Fig. 9).

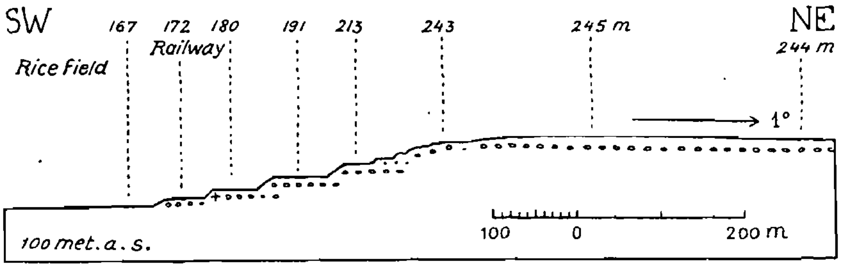

Fig. 9. The gravel terraces 1 mile west of Chalsa railway station (heights in meters approximate). + = gneiss boulder of 2 cubic meters, at 10 km from the mountain border.

The top terrace is the best developed and the most extensive. West of Chalsa, as seen from a distance, it seems to be warped. Its southern side converges with the lower terraces, whereas the northern side shows a counter-dip towards the Himalaya of 1—2 degrees. The road from Chalsa to Matiali, after climbing in curves to the hill 859' of map $78\frac{B}{13}$ follows this gentle counter-dip in a northern direction for about 2 miles. Matiali is in a synclinal depression[1]. Thence the gravel surface rises uninterruptedly towards the mountains.

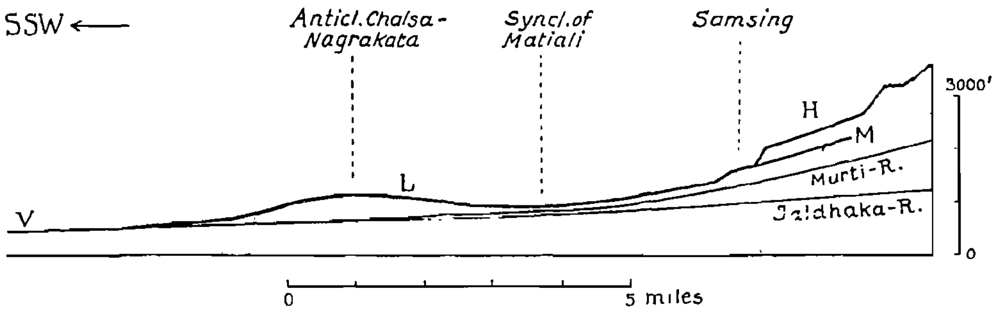

Fig. 10. Warping of the Quaternary gravel terraces at Matiali, east of the Tista. (Heights 5 times exaggerated). V = bottom of the valley; L = Low terrace; highest level (Nagrakata terrace); M = middle terrace (Samsing terrace); H = High terrace (Kumai terrace). (At Mal-Chalsa the southern limb of L-terrace is cut out in the shape of secondary steps as shown in Fig. 9).

A similar vast terrace, with its cliff towards west, entirely planted with tea, follows east of the Jaldhaka river. If there be no counter-dip, at least the original southward slope has been changed into a level platform of 1150' (Fig. 8). According to the above-mentioned map the river has cut its way 450' down through the Nagrakata terrace.

Instead of an uniform subsidence of the alluvial plain, we thus find a longitudinal zone of relative upheaval along the Siwalik border. This anticlinal warping strikes E 15° N and illustrates a recent tectonic movement probably still going on.

Following up the Murti River at Samsing, we come to higher terraces. Once more the slope of the river-bed diverges from that of the terraces, which rise more rapidly towards the mountains, namely as much as 5° and even up to 10°. A strongly marked gravel terrace is that of Samsing forest bungalow. It rises from 550—660 meters and to about 130 meters above the river and is indicated as the Middle terrace (M) in Fig. 7 and 8. It seems either to continue at the Nagrakata plateau, or else is stratigraphically slightly higher.

[1] The hills of Matialy, 200—250' high (at 1153'), may be relics of a higher terrace and would be worth a special study.

About 80 meters higher still is the terrace of Kumai village on the east side of the Murti river (Fig. 8), which rises 5–10° towards the mountains.

These two higher terraces M and H are composed of extremely coarse gravel material with rounded blocks of micaschist and gneiss up to several cubic meters.

Boulders of extraordinary size are also washed down into the actual river. Several of them below the forest bungalow reach over 10 cubic meters, and one a little further up was estimated at nearly 100 cubic meters. This enormous erosive power is due to the rainfall of this most rainy country of the world (10–12 meters per annum).

The Himalayan Border at Kathgodam, West of Nepal

Following the foot of the mountains with the survey maps $53\frac{O}{SE}$ and $53\frac{O}{SW}$ at hand, our first surprise was to find the lower Siwaliks with a perpendicular strike to the general trend of the Himalayan border. This is the case at the entrance to the Jam Valley 7 miles SE of Kathgodam, where the violet and green clays are exposed with a dip of 60° to WNW and NW (Fig. 11).

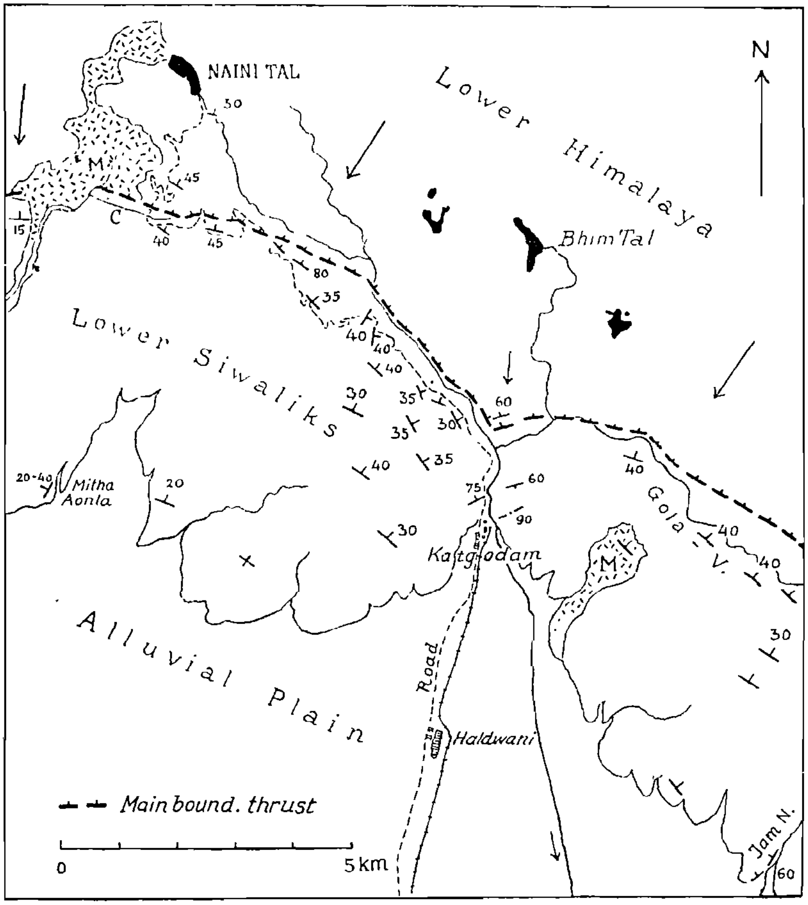

Fig. 11. Tectonical Sketch-map of Kathgodam.
C = Calcareous sandstone; M = Mountain slide, Lakes black. Some strikes and dips and eastern part of main boundary thrust after MIDDLEMISS 1891.

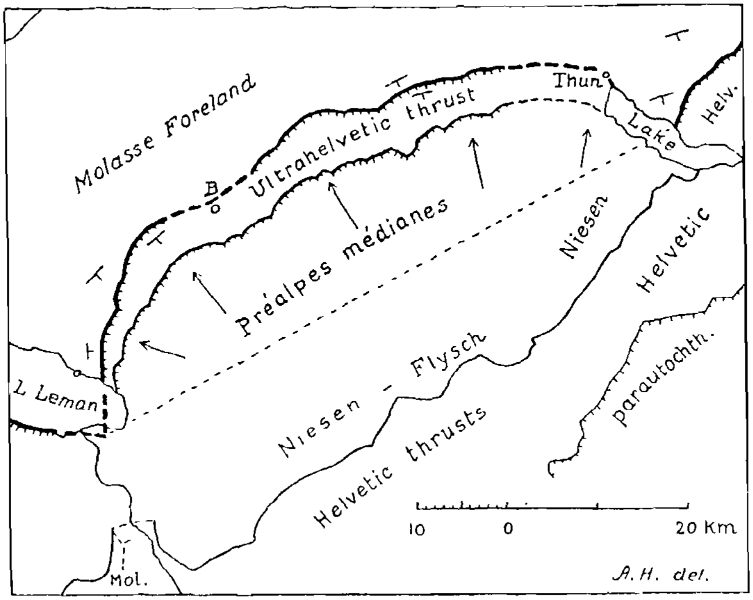

Fig. 13. The Alpine Border of Western Switzerland.

below the red Mandali formation. But at Rajpur, as already mapped in 1864 by MEDLICOTT (39), the Himalayan border jumps as much as 8—10 km to the south and down into the Dehra plain where it forms the Kalanga hill 3089'. No corresponding displacement is seen along the Siwalik crest in front of it.

As seen already at a long distance, the Siwalik border continues with a regular northwestern strike, as if it had not felt anything of the approaching Himalayan thrust. New observations may determine many more similar cases which formerly could not be understood.

To explain the old erosion of the subalpine Molasse, the writer, in 1906, supposed that in Miocene time the main currents flowed along the strike behind the molasse border ranges. The younger Himalaya seems at present to be in that condition with its Duns, as such longitudinal valleys behind the Siwaliks front ranges are called. Indeed, if the Himalaya advances, the Duns will become filled up tectonically, and the structure will largely depend on the former erosion of the foreland, more than vice-versa.

THE GREAT THRUST FOLD OF DARJEELING

Tectonical Features

The present knowledge of the swimming Darjeeling gneiss is based on the excellent work of MALLET, published in 1874 (Mem. Vol. XI). It is true that MALLET, according to the general tectonical conception of that time, regarded the Darjiling series as normal and autochthonous. He was, however, much surprised to find that in contrast to all other known countries, the degree of metamorphism increases upwards i. e. according to his idea towards the Darjiling gneiss, which he considered as the youngest formation (Fig. 14).

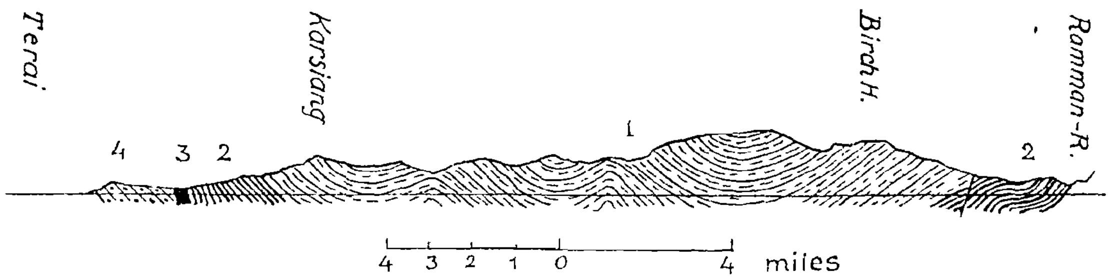

Fig. 14. The first section of Darjeeling by MALLET, 1874.
1 = Sikkim Gneiss; 2 = Daling series; 3 = Damuda; 4 = Nahan Group (Tertiary).

Since then all observers have confirmed the idea that the gneiss overlies the Daling series of schists and quartzites which are exposed all along the deep transverse cut of the Tista river. The coal-bearing carboniferous Damuda series not only underlies the certainly older Daling schists, but is in itself in a reversed position. Indeed, C. S. Fox (16) discovered just above the railway station of Tindharia on the Darjeeling road a basal conglomerate (Tillite?) in the orographically upper part of the coal bearing Damudas (Fig. 15).

The latest and conclusive discussion with some new data was furnished by AUDEN in 1935.

Wherever the series is traversed from the gneiss down to the Dalings, a transitional zone of some hundred meters thickness is found in the form of mica schists. They are frequently full of garnet, and interbedded with quartzite. Following up the previous observers, we again studied this transition in the south, the east and the north of Darjeeling. As already stated by AUDEN, WAGER's section of 1934 indicating a sharp thrust of the gneiss is incorrect. We must come to the conclusion that the Darjeeling gneiss and its continuation in the Kangchenjunga massive belongs to a huge recumbent anticline thrust from N to S over a visible surface of more than 80 Kilometers (Plate I).

While the Darjeeling gneiss is underlain and surrounded by younger sedimentaries, the huge Kangchenjunga massive represents the root zone of the great Darjeeling thrust fold. The valuable observations of v. LÓCZY, HAYDEN, HERON, WAGER and AUDEN of a normal series of Permocarboniferous (Everest limestone and Lachi series), Triassic (Tso Lhamo series) and fossiliferous Jurassic (which further north in Tibet is crowned by fossiliferous Cretaceous and Nummulitic) and their northern dip are conclusive. G. DYHRENFURTH (14 p. 298) found the northern-most

limestones and dolomites below the gneiss in the Lachung Valley which is at 90 km distance from the frontal part of the thrust gneiss. His section p. 296 shows a thrust of over 100 km. We do not yet know how far underneath the surface the Dalings and Mica schists penetrate towards North below Kangchenjunga. Possibly the march of the gneiss towards the Indian plain is even more than 120 Kilometers.

In principle we thus come to the same conclusion as L. v. Lóczy, who in 1907 reconsidered his observations of 1878 and whose conclusions were so long ignored (compare Fig. 14, 15 and Pl. I). The highest mountains correspond to the back of the largest known thrust fold of our globe. Indeed, the tectonical position of Choma Lungma (M. Everest 8982 meters) is that of Dodang Nyima on the northern part of Kangchenjunga, where A. M. Heron in 1922 also found a normal superposition of a Permian to mesozoic series upon the northerly dipping gneiss.

G. O. Dyhrenfurth (14) was mislead by a limestone series at Dodang Nyima north of Kangchenjunga which he took as reversed Cretaceous thrust upon the gneiss, the granitic intrusions of which he regarded as Tertiary.

The present sections of Kangchenjunga and Chomo Lungma (Pl. I) are only preliminary, and only partly based on our personal observations. They illustrate, however, the known data of topography and geology of the present time, and are drawn without exaggerations[1]. Detailed studies and mapping will certainly bring to light more complications.[2]

Regarding details of structure, we may mention a most beautiful parabolic syncline with 14° pitch to NE subdividing locally the mica schist series below point 4860′, 2½ km SE of Kurseong on the Darjeeling road. It belongs to the reversed frontal part of the great thrust fold, and was laid bare by a quarry of building stone. On its West side a slickensided southerly dipping thrust fault was visible which has cut off the parabolic quartzite syncline. (Fig. 16 and photo 4, Pl. VII). This syncline is not only of local interest. It shows how the hardest rock of the Himalaya has been deformed without fracture (bruchlos) and how each quartzite layer mathematically thins from the axes towards the limbs. This fact only can be explained by very high pressure. But if we can hardly believe, that

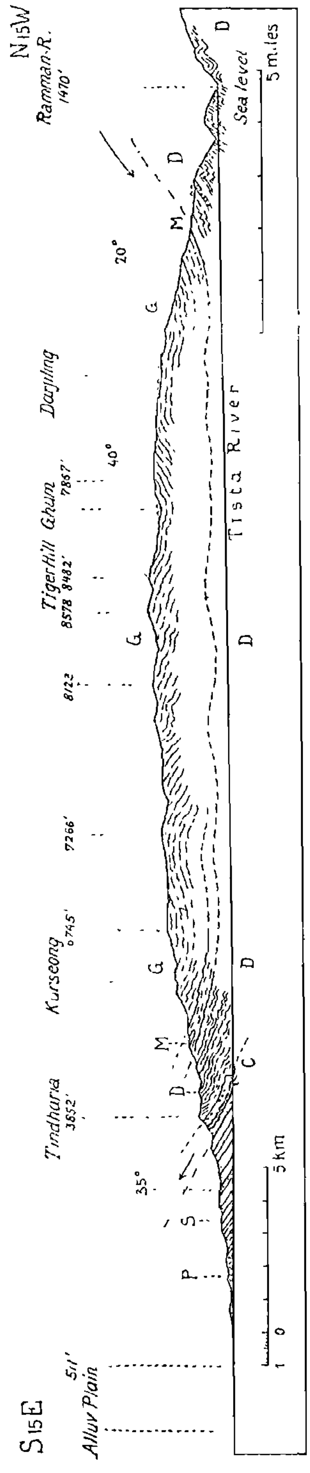

Fig. 17. Section of Darjeeling.

G = Darjiling gneiss; M = Mica schists with quartzite; D = Daling series, phyllites and quartzite: C = Carboniferous (Damuda series) with anthracite; S = Siwaliks, miocene-pliocene; P = Pleistocene boulder beds.

[1] Unfortunately Hayden's sections are without a scale, and the heights are exaggerated.

[2] In NE Sikkim, for instance, Auden (4, pl. 6) has figured a recumbent anticline of the gneiss. Similar complications may be found at Kangchenjunga.

at the margin of the great thrustfold 5000 or more meters of superposed rocks have existed, we must question whether the folding was made in great depth farther north and then had been shifted passively towards south.

The syncline of Kurseong may be only one of the many conceiled cases of repetitions and thrust planes within the series which, as a whole, is regarded as reversed. In any case, the question arises, how far down the Dalings may be regarded as belonging to the reversed series. On an excursion all along the Tista, the intensely folded series of schists and quartzites did not give the impression of being reversed. Possibly, by deep boring underneath the Dalings of the Tista, a similar progressive metamorphism would be found downward as it occurs upward at the surface.

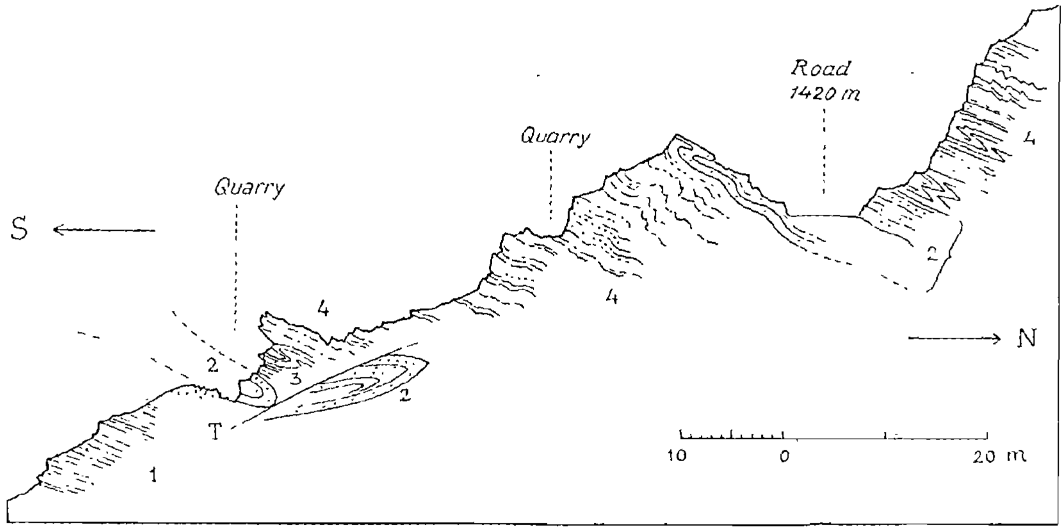

Fig. 16. Details of the reversed series of Mica schists below the Darjeeling gneiss on the road 2½ km SE of Kurseong. (Conditions of April 4th, 1936).

1 = mica schists with psammite gneiss; 2 = quartzite; 3 = banded gneiss with quartzite and psammite gneiss; 4 = mica schists with garnet, and quartzite; T = local thrust plane

Note: axes of minor folding in NE direction!

In his "Traverses" of 1935, AUDEN emphasizes the presence of Aravalli structures found in the Darjeeling gneiss. Indeed, the north-eastern strike of this range in Indian Gondwana is still recognizable in the Lower Himalaya. Before having been acquainted with AUDEN's paper, the writer, in 1935, was puzzled by a cross-strike of the gneiss on the Darjeeling road, in the ravine one mile north of Kurseong. There, the Darjiling gneiss strikes for some distance N to NNW and NNE with a westerly dip as much as 75—80°. Also the minor folds of the mica schists SE of Kurseong (Fig. 16) strike NE. Numerous cases of abnormal strike are indicated in GARWOOD's map of Kangchenjunga (17). Such an abnormal NNE strike determines the western border of the Sikkim window. According to GARWOOD the gneiss strikes N instead of E over almost the whole of the Kangchenjunga massive. Similar cross strikes to the Himalayan trend were also found on a larger scale by AUDEN in the Arun Valley of Nepal and in Garhwal. The resemblance of these metamorphic rocks to those of the Peninsula, and the presence of the Damuda series, with its coal seams and *Glossopteris* leaves, as the youngest division of the thrusted eastern Himalaya also confirmed HAYDEN's conclusion (in 8, p. 291) that "the Hima-

layan chain is in part made up of true representatives of the oldest known group of rocks, and that these are merely the northerly extension of the similar rocks of the Indian Peninsula".

Such structural remnants of an Aravalli-strike (NE) are apparently the cause of many irregularities in the position of the gneiss and of the irregular boundary with the overlying sedimentary formations of the Tista Valley and along the Tibetan frontier.

Tectonical Essay of Mt. Everest

The tectonical position of Kangchenjunga being now explained and figured in its main lines, we may compare it with what is known of Mt. Everest (Plate I).

According to Auden, the frontal part of the Himalayan thrust is practically the same as that of the Darjeeling region: the Siwaliks form a frontal anticline upon which is thrust a second series of Lower Siwaliks. The thrusting is similar again and the Himalayan formations (Damuda-Dalings-micaschist-gneiss) are at least partly reversed. Similar to the window or half-window of the Tista, the Tamur- and Arun rivers form half-windows cut into the Dalings and extending 50 km towards north, underlying the gneiss.

The middle part of the Arun valley, which is probably the deepest transverse gorge of our globe, has never yet been visited by a geologist. However, looking from the East, everything points to the conclusion that it is the western continuation of the Singalila crest and thus also formed of gneiss, with gentle inclinations of its stratification.

We owe the knowledge of the Tibetan side of Chomo Lungma (Mt. Everest) to Odell, Heron and Wager. Nobody ever doubted that the Chomo Lungma massive is the western prolongation of Kanchenjunga. However the summit with its permo-carboniferous limestones (Lower and Upper Everest limestone of Wager) does not correspond exactly to the gneissic summit of Kauchenjunga, but to its northern part, especially to Jongsong or Dodang Peak as already observed by G. Dyhrenfurth. The continuation of the strike towards West of Kanchenjunga summit leads to a region of 25—30 km south of Mt. Everest, where the gneiss has been denuded to summits of 7000 meters and less.

The Tibetan zone of the Everest section with its normal folding also corresponds to that on the northern side of Kanchenjunga, the Eocene syncline of Shekar Dzong being equivalent to that of Kampar Dzong, although they may not be in direct continuation.

We thus conclude that the highest mountain of our globe is weathered out of the normally stratified back part of the greatest known thrustfold which we have called after Darjeeling, the starting point of all expeditions and geological investigations in the eastern Himalaya.

The Rock-Types of Darjeeling

(by A. Gansser)

The whole series of rocks which can be studied almost continuously from the Tista River up to the heights of Darjeeling, shows a passage from nearly non-metamorphic shales up to the katametamorphic type of sillimanite-gneiss. Three subdivisions may be distinguished: (1) Daling schists with quartzite, (2) garnetiferous mica schists and (3) the typical Darjeeling gneiss. Some new observations may be added to the description of former observers.

1. The Daling Schists

The characteristic rock is a greenish schist. The least metamorphic types may be called clay-slates. They usually alternate with greenish quartzitic sandstone layers. The impurer ones show a somewhat higher metamorphism. This is partly caused by selective metamorphism, partly by lack of interreaction in the case of pure quartz rocks and pure argillites.

An average type of green schist shows the following composition (analyst Prof. J. JAKOB):

SiO_2	54.73
Al_2O_3	22.39
Fe_2O_3	3.05
FeO	4.01
MgO	1.61
MnO	0.02
CaO	0.59
Na_2O	1.79
K_2O	5.43
TiO_2	0.80
P_2O_5	0.14
H_2O+	5.42
H_2O-	0.18
	100.16
si	202
al	48.5
fm	30
c	2.5
alk	19
k	0.67
mg	0.30
ti	0.02

To facilitate the comparison with other rocks, the molecular values according to NIGGLI[1] have been calculated and compared with the values of a normal clay slate:

	si	al	fm	c	alk
Normal argillite:	200—500	35—50	30—50	1—10	8—20
Daling schist:	202	48.5	30	2.5	19

The above figures show that the Daling schist is chemically comparable with a clay-slate or argillite, the variability in silica excepted, which derives from the variable amount of quartz sand. The above example shows a minimum of quartz.

Another type may be defined as sericite-chlorite-quartzite. The characteristic minerals are quartz in the shape of small round grains which show intense undulose extinction. The larger grains are embedded in a fine ground mass of sericite with almost colourless scales of chlorite. The latter is slightly pleochroitic (yellowish, green). As a primary accessory rutile is present (partly leukoxenized), enriched in patches. Some large idiomorphic tourmaline crystals with brownish pleochroism may be considered to be secondary. Epidote grains and a limonitic substance are more sporadic. The texture of the stratified rock is blastopsammitic to porphyroclastic.

The next type is a biotite-chlorite-schist with epidote, of a stronger metamorphism. The schistosity is obvious. On the warped surfaces of the strata which are of a green lustre, the small biotite scales are recognized even macroscopically. Together with quartz of slightly undulous extinction, chlorite and biotite are the main representatives. Usually the mica is concentrated in fine layers and associated with chlorite which seems mainly to be formed of biotite. Epidote and clinozoisite are accessory, as well as the subordinate sericite. Secondary accessories of fine distribution are tourmaline, apatite, rutile and orthite. The texture is granoblastic to lepidoblastic and of characteristic crystallization schistosity (Kristallisationsschieferung).

An increase of sericite leads on to the sericite-chlorite-schists with biotite. Compared with the less sericitic schists, they are less green. The surface frequently shows fine furrows. The quartz is very fine-grained and concentrated in thin layers. The biotite is frequently pleochroitic, green and partly transformed to chlorite. As an accessory mineral we find clinozoisite in form of long idiomorphic stalks, usually nicely separated from the rounded grains of epidote. Ilmenite occurs in fine scales. Tourmaline of brown colour is sporadic. This rock-type is still blastopsammitic and of crystallization schistosity.

With increase of sericite and the occurrence of garnet, we pass on to the next group of rocks:

2. The Garnetiferous Mica Schists

This group is multifarious. While the former one was of epimetamorphic character, the minerals of this group are mostly of the meso-type.

The quartzitic types show the least complicated mineral association, though being even macroscopically different from the Daling quartzites The greenish colour has disappeared, and in place of the argillaceous rocks the micas are already well defined muscovite and biotite. Beginning the description with the more simple types which are developed above the Daling quartzites, we come to the garnetiferous muscovite-biotite quartzite. Associated with

[1] P. NIGGLI, F. DE QUERVAIN, R. U. WINTERHALTER, Chemismus schweizerischer Gesteine. Beitr. z. Geologie der Schweiz, Geotechn. Serie, XIV, 1930.

abundant quartz of irregularly intergrown though little kataclastic grains is an interesting garnet of a skeletal relictic aspect. On the edge and in the cracks limonite has been formed. The only rare inclusion is biotite (Phot. 78, Pl. XXV). The rock, on the whole, is of massive appearance under the microscope, though showing macroscopically the original stratification. The additional schistosity made by the regular orientation of the micas is counterbalanced by the garnets which form wart-like knots on the rock surface. When the content of micas increases, the highly micaceous quartzite is reached, of which the biotite is less abundant and garnet non-existent or only sporadic. The quartz is rather less intergrown, but of distinctly undulatory extinction. Folding in detail is frequent and may pass on to "helicitic" structure.

Decrease of quartz leads to the real schists. They usually carry garnet and are accordingly less minutely folded. The strong lustre is caused by sericite; the warped mica scales are characteristic. The simplest type is the garnet-muscovite-biotite schist. Yet there is quartz in places of a pavement-like texture and of little undulose extinction. Garnet is frequent, and idiomorphic, though rich in drop-like quartz-inclusions. They frequently form S-shaped figures in the centre. The biotite forms elongated scales which contain inclusions of zircon with pleochroic haloes. The colour of the biotite is the ordinary brown. The muscovite is irregularly built and frequently shows dust-like limonitic inclusions. As accessories we find magnetite, ilmenite, and a slightly zonary tourmaline.

On the distinctly schistose rock the elongated biotite crystals are even macroscopically recognized and might be taken for staurolite at first sight. The kyanite-staurolite-garnet-muscovite-biotite schist is to be mentioned as a type illustrating the meso-conditions. Such rocks are of a fairly wide distribution, though frequently only staurolite is recognized. Staurolite and kyanite are easily recognized on the weathered surface. The latter may become concentrated in lenticular quartz veins forming individuals up to 10 centimeters in length. The main minerals are: muscovite, usually of irregular scales and containing dark graphite-like inclusions. The quartz grains are of slightly undulose extinction and of irregular lobate contours. The garnet forms large rounded grains including magnetite. The rims and cracks are limonitised. The biotite is of a light brown to reddish brown pleochroism. The scales are larger than those of the muscovite and frequently of polygonal position around the garnet. Inclusions of zircon are again surrounded by haloes. The kyanite shows the characteristic cleavage, with an extinction $Z/c = 28—30°$. The staurolite is distinctly pleochroitic from light yellow to dark yellow. In its centre may be dust-like inclusions. Both staurolite and kyanite form large porphyroblasts. Magnetite, limonite and rutile occur as accessories. The texture is grano-lepidoblastic, partly porphyroblastic, the structure stratified to schistose.

The last mentioned rock-types show a striking resemblance to the crystalline para-zones of the lower Penninic thrust sheets of the Alps, especially to certain occurrences of the Canton Ticino, such as on Pizzo Forno.

We have passed from the epimetamorphic Dalings to the mesometamorphic mica schists, and now come to rocks of still higher metamorphic grade.

3. The Darjeeling Gneiss

General descriptions of the Darjeeling Gneiss were published by MALLET (38), DYHRENFURTH (14), AUDEN (4) and others. The following remarks are presented in order to furnish a basis for a comparison with similar rocks in other parts of the Himalaya. The garnetiferous psammitic gneiss corresponds to the garnetiferous quartzitic mica schists. Its sedimentary origin is easily recognized even macroscopically. It is usually banded by light gray, more quartzitic layers which alternate with darker layers rich in biotite.

The garnetiferous muscovite-biotite-psammitic-gneiss is characterized in general by the following minerals:

Quartz is predominent. The large grains of lobate contours are distinctly undulatory. Oligoclase - andesine with twin-lamellas is less abundant. Among the micas the biotite of light brown to red-brown pleochroism predominates. Like the muscovite which always joins the biotite, it borders the quartz in a lobate shape.

The most important amongst the accessory minerals is an idiomorphic garnet with frequent quartzite inclusions. Apatite is present in rather large round grains. Ilmenite is joined to the biotite. The sporadic accessories are zircon and rutile enclosed in biotite, the former again with pleochroitic haloes.

The rock is stratified, the texture granoblastic. Beside psammitic gneiss there are garnetiferous muscovite-biotite gneisses, rich in mica and only distinguished from the mica schists by the presence of feldspar. The quartz grains are more polygonal and show little undulatory extinction.

Albite-oligoclase is very subordinate. Dark brown biotite predominates amongst the micas. Its marginal zones are partly bleached. The muscovite is "sprinkled" with tiny dust-like particles. Most interesting is the shape of the garnet (Phot. 79, Pl. XXV). The many Quartz inclusions are of S-shape. The margin is fringed. Frequently even the whole garnet crystals are S-shaped. Staurolite is of special interest amongst the accessories. It forms small crystals and is characteristic of the already mentioned passage from the mica schists.

The normal type of Darjeeling gneiss may be defined as a more or less injected garnetiferous biotite-psammite gneiss. The injected rocks, although characteristic, are very varied. As for the normal type, the primary stratification is obliterated by the various veins of injection which are chiefly made of quartz and oligoclase-andesine. The quartz grains of the veins are intergrown. The biotite predominates over the muscovite. The latter, however, is recognizable even macroscopically. The garnets form larger imperfectly idiomorphic grains which give the granoblastic rock a somewhat porphyroblastic appearance.

The gneisses with sillimanite which may be regarded as the katametamorphic representatives of the staurolite-kyanite mica schists, may also be regarded as normal types.

Such a typical sillimanite-biotite-gneiss is constituted of the following minerals:

Quartz predominates in the shape of lobate grains which, howewer, show slight or no undulatory extinction. The feldspars are not well formed. The albite only rarely shows twin-lamellas. Orthoclase-like alkali feldspar is present with a small optic-axial angle. Beside the reddish brown biotite, sillimanite is present in tiny needle-like aggregates. Larger individuals with clear transverse cleavage are not frequent. The latter may be slightly brown. Muscovite, apatite and magnetite are accessories. Zircon with haloes is enclosed in biotite.

The granoblastic texture tends towards a fibroblastic appearance because of the abundant presence of sillimanite. The structure is irregularly schistose.

The two types described above have been analysed by Prof. Dr. J. Jakob, with the following results:

Nr. 2 Garnetiferous biotite psammite gneiss (little injected) Nr. 3 Sillimanite-biotite gneiss

	2	3		2	3
SiO_2	66.01	66.68	si	294	330
Al_2O_3	16.72	16.87	al	44	49.5
Fe_2O_3	1.41	1.87	fm	29	31.5
FeO	4.55	4.39	c	4	3.5
MgO	1.10	1.85	alk	23	15 5
MnO	0.01	0.08	k	0.56	0.66
CaO	0.81	0.68	mg	0.25	0.20
Na_2O	2.37	1.12	ti	0.37	0.38
K_2O	4.59	3.27			
TiO_2	1.10	1.00			
P_2O_5	0.05	0.09			
H_2O+	1.41	1.96			
H_2O-	0.00	0.18			
C	trace	—			
	100.13	100.04			

The two analyses confirm the results of the observations in the field and under the microscope that the Darjeeling gneiss is a partly injected sediment of argillaceous origin. Comparing the above analyses with those of the Alpine rocks, the closest resemblance to this Himalayan section is found in some biotitic injection gneisses of the region of Bellinzona[1] as well as with the biotite-plagioclase gneisses called Ceneri Gneiss[2] a little further south. These rocks macroscopically and microscopically resemble closely the Darjeeling Gneiss, a fact which struck the author's eyes at first sight.

The original sedimentary material was a Daling-like clay-slate, as was to be expected after the microscopic research. It is therefore of special interest to compare the analysis of the Dalings with the different Darjeeling- and Alpine gneisses:

	1. Daling-schists	2. Biotite-Sillimanite Gneiss	3. Garnet-biotite-psammite Gneiss	4. Ceneri Gneiss (Alps)	5. Injection Gneiss (Alps)
si	202	330	294	301	307
al	48.5	49.5	44	42.5	43.5
fm	30	31.5	29	30	21.5
c	2.5	3.5	4	6.5	6.5
alk	19	15.5	23	21	28.5
k	0.67	0.66	0.56	0.49	0.52
mg	0.30	0.20	0.25	0.45	0.51
ti	0.02	0.38	0.37	6.5	1.2

The general accord is striking. The relatively large difference of the si- and alk values may be caused by the different grade of injection. Since the Dalings also vary in their quartz content, their low si-figure is of no significance. A special harmony is found between analysis No 3 and that of the Ceneri-Gneiss (4) which also is a biotite gneiss of predominant paramaterial. The next chapter will show that other phenomena characteristic of the Darjeeling Gneiss, are also found in the Ceneri-Gneiss of exactly the same kind.

The biotite-sillimanite gneiss (2) differs from the garnet-biotite gneiss chemically by the alk value. The abundant occurrence of sillimanite is represented by the surplus of clay (al-alk) which is as much as 34 units, whereas in the garnet-biotite gneiss it is only 23 units. The higher alk of the biotite-psammite gneiss accounts for the injection.

As mentioned before, the Darjeeling gneiss is apparently the kata-metamorphic representative of a slate similar to an argillite. This view is confirmed by the chemical analysis.

Both rocks are characterized by a difference of al-alk of 30 or more. A great similarity is also shown by the k and mg values.

The gradual passage from the epimetamorphic Daling slates through the mesometamorphic kyanite-staurolite-garnet-mica schists to the katametamorphic sillimanite gneisses of Darjeeling, observed in nature, seems thus also to be confirmed by chemical analysis.

4. The Limesilicate Inclusions of the Darjeeling Gneiss

According to our observations, the presence of limesilicate (calcsilicate) inclusions is a widespread phenomena in the Darjeeling gneiss. Usually there are lenticular bodies of about 20—25 centimeters, the ends of which are bent or crumpled (Phot. 8,9 Pl. VIII; 11 Pl. IX). In other places they form bands which are folded conformably to the surrounding gneiss. In every case the gneiss clings to these inclusions.

[1] NIGGLI and others, l. c. on p. 17.
[2] R. BÄCHLIN, Geologie und Petrographie des M. Tamaro-Gebietes. Schweiz. Min. Petr. Mitt., Bd. XVII, 1. 1937.

At the contact the gneiss is somewhat enriched by biotite. The occurrence of layers or zenes rich in garnet and diopside gives to the lenticular bodies a somewhat concentric appearance. Usually the garnets are already macroscopically identified. An extremely zonal structure as described of similar occurrences in the Ceneri-Gneiss of the Alps[1] was, however, not observed.

Under the microscope the following mineral composition is revealed:

The adjacent rock is a normal biotite gneiss, partly injected. At the contact with the inclusion the biotite is enriched. Then follow large intergrown lobate quartz grains with little biotite, some garnet and small grains of titanite. The border to the inclusion is sharp. Beside the quartz grains follows a border of bytownite with welldefined twin-lamellas. The plagioclase is joined to green hornblende. Titanite and garnet in large round xenomorphic grains are also present. The latter are filled in a sieve-like way with quartz inclusions. Together with the garnet there is also a slightly green diopside of relictic shape.

Macroscopically we observe a whitish zone dotted with red and green spots.

The next, more reddish zone, often forming the centre, about 5—10 mm from the boundary, shows under the microscope a reticular appearance of garnet. Large individuals are lacking. With this garnet bytownite, diopside and even some quartz are associated. Titanite usually forms larger xenomorphic grains. No free carbonate occurs.

In general it is surprising that the bytownite, and partly also the garnet are of a relictic shape caused by quartz which includes and surrounds those minerals. The microscopic aspect points to an ingress of quartz which might be in connection with the injection of the gneiss.

Summing up, the following mineral paragenesis of a limesilicate inclusion is observed, from the adjacent gneiss to the centre of the lenticular body:

1. Quartz, oligoclase-andesine, biotite, garnet (country rock)
2. Quartz, little andesine, little biotite, garnet, titanite > contact
3. Bytownite, green hornblende, garnet, quartz, titanite
4. Bytownite, garnet, diopside, quartz, titanite
5. Bytownite, quartz, fine reticular garnet (titanite).

Other similar occurrences have shown the same composition. In places the garnet is larger and contains less quartz inclusions, although the bytownite still abounds in them. The diopside here and there shows marginal transformation into a slightly greenish pleochroitic hornblende.

Besides the frequent inclusions described above, some special types will be mentioned.

An extreme abundance of garnet leads to a quartz-bearing garnetite. Some pieces collected in the Murti River show red-brown idiomorphic garnets up to 2 centimeters each. Under the microscope we recognize inclusions in rows of drop-like quartz connected with swarms of longitudinal magnetite grains. As in the case of the quartz, they are distributed in the garnets in a fluidal shape. Both these inclusions are usually concentrated at the core of the garnet.

Other inclusions in the gneiss are more basic lenticular bodies, rich in hornblende. They are characterized by their irregular banding (Bänderung). The different layers of garnet, hornblende and diopside are even macroscopically distinguished, as described below:

1 The amphibolitic zone shows a prevailing amount of olive to bluish-green pleochroitic hornblende. There are also quartz, anorthoclase-like alkalifeldspar (described in the next chapter), garnet and epidote - clinozoisite.

2. The peridotitic zone is of a more complex nature. Besides the alkalifeldspar, which at first appears like undulatory quartz, there is much brown biotite, epidote - clinozoisite and

[1] R. Bächlin, Geologie und Petrographie des M. Tamaro-Gebietes. Schweiz. Min. Petr. Mitt Bd. XVII, 1, 1937.

quartz. Garnet is very abundant here too. It is usually concentrated in layers, and full of central inclusions of quartz and feldspar.

An increasing amount of hornblende leads to lenses of real amphibolite. Their hornblende is pleochroitic: X = pale green; Y = olive green; Z = blue-green. The extinction of z/c is about 20°. The reticular inclusions, mainly of plagioclase and quartz, are remarkable.

Other, only local inclusions in the gneiss shall not be described.

5. Pegmatites and Basic Sills

Frequently dikes of pegmatite and aplite are found traversing the gneisses in various directions. They may also occur in the garnetiferous mica schists. At Badamtam, north of Darjeeling, such a dike is 5 meters thick. Here, as in the gneisses themselves, the dikes are mainly muscovite-tourmaline pegmatites. Locally they may contain garnet and some biotite. The pegmatite sills are regarded as the last intrusions in connection with the injection, or may be little younger (Fig. 17).

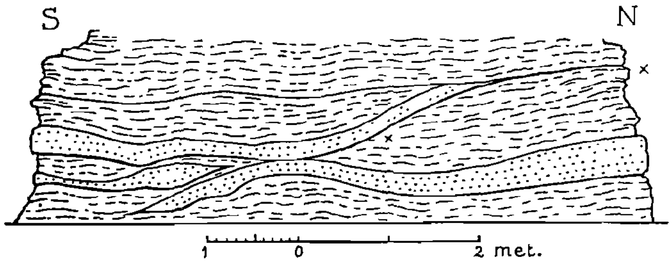

Fig. 17. Aplitic Intrusions in the Darjeeling Gneiss at Ghum (Trail one mile NE of point 7867'). x = sliding plane.

Sills of basic rocks are rare, and usually restricted to the passage zone between garnet-mica schists and real gneiss. The amphibolitic rocks are frequently remarkably rich in quartz.

An example of quartz-actinolite-amphibolite of irregular banding from Badamtam reveals under the microscope as the essential mineral an actinolitic hornblende. The pleochroism is X = yellowish; Y = greenish; Z = pale bluish-green; Z/c = about 15°. The shape is not well defined. The quartz forms intergrown grains. The plagioclase is less abundant and of the labradorite type. Both plagioclase and hornblende carry abundant inclusions of quartz. Epidote-clinozoisite is fairly abundant. The core of it is always richest in Fe- content. As accessories there are apatite, titanite and rutile, the latter frequently in the shape of inclusions in the titanite.

Another basic sill of the same locality is of a more complex composition and deserves special description, although superficially it is not different from the type mentioned above. The streaky distribution of hornblende and biotite is striking. Under the microscope we first recognize an actinolitic fibrous hornblende. In addition there is a feldspar of an uncommon amphibolitic rock. The irregular grains show an undulatory extinction and are of a cryptoperthitic aspect. They possess an indistinct microcline-like reticulation. Peculiar also is the low refrigence similar to that of an alkali-feldspar. The measurement on the universal stage led to the recognition of a tricline (cleavage!) alkalifeldspar, of a negative angle 2 V = 50—54°. According to this optical character it must be an anorthoclase.

The anorthoclase is the only feldspar of this type of basic rock. Diopside is present in short light green prisms. The biotite is pale yellowish to brown. The quartz grains show slightly undulatory extinction and of lobate contours. The accessories are epidote, apatite with sporadic titanite and limonitic material.

Such abundance of anorthoclase in a metamorphic rock is unusual. As far as we know, only one such case has been recorded, namely from an amphibolitic rock of the Pyrenees[1]. There it is "un schiste amphibolitique a grain très fin, qui alterne avec des gneiss à deux micas et qui est traversé par quelques filons granulitiques emanant d'un massif granitique situe un peu plus au sud". The anorthoclase appears in the granitic veins of injection within the amphibolite and belong to the latter. In the rock from Darjeeling however, — which is an anorthoclase — bearing diopside-actinolite, the anorthoclase is not bound to the few quartzose layers of injection, but is frequently interbedded between the hornblende layers. As in the case of the Pyrenean quartz-bearing amphibolite, the present rock too seems originally to have been a sedimentary rock wich subsequently was transformed by the same injection of the Darjeeling gneiss. This interesting occurrence of anorthoclase in a metamorphic rock is indirectly explained by injection.

6. Some Petrographical Observations in Sikkim

On a hurried excursion we had the chance to get a glimpse of the muscovite-biotite-granite gneisses on the motor road just below Gangtok, which dip 30—40° towards E and NE. They are mentioned only as a completion to the study of the Darjeeling gneiss.

Rising through the Dalings, a similar increase of metamorphism as in Darjeeling is recognized. The granite gneisses are interbedded in garnet-staurolite-mica schists. They form the basal part of the general gneiss sheet which corresponds to that of Darjeeling. Macroscopically the gneiss is white with streaks of mica.

Under the microscope we recognize much quartz which is intergrown with all other minerals. Orthoclase and microcline are frequent. The reticular structure is distributed in patches. The albite shows well-defined twin lamellas. Muscovite and biotite, the latter of olive green to yellowish pleochroism, are only accessories. Apatite and magnetite are very subordinate. When the contents of biotite increases, the rock passes to the biotite-alkali-feldspar gneisses which are less massive than the former types.

These rocks are regarded as injection gneisses. Accordingly an ingress of silica is verified under the microscope.

Besides these typical equivalents oft he Darjeeling gneiss another gneiss was encountered on the road near the Tista at Tunglubong. It may be called muscovite-biotite-alkali-feldspar gneiss (Augengneiss). It is even macroscopically distinguished from the above mentioned types by the lack of injection character. It is an uniform body of typical orthogneiss, of about 100 meters thickness. The dip is 25—50° to the north. It must be emphasized that this gneiss is included in the Dalings (sericite-chlorite-quartz schists). Although the direct contacts are not exposed, they must be considered as being of tectonical origin.

Marginally the gneiss body is more schistose, greenish, and transformed along shear planes to a chlorite schist. The central part of the gneiss shows large eyes of quartz and alkali feldspars. The orthoclase is perthitic. The microcline too shows perthitic reticulation. The biotite predominates the muscovite. Both micas are minutely scaly (feinschuppig) and form lenticular trains around the quartz-feldspar eyes.

Towards the lower contact the greenish colour increases. Except for its content of chlorite and epidote, it still resembles the central part, though showing more epimetamorphism. The biotite is mainly chloritized, the mica sericitized. The large orthoclase is unmixed in the shape of chequered albite ("Schachbrett-Albit"). The granular epidote is joined to chlorite and sericite.

[1] Gysin, M. Sur la présence de l'anorthose dans un schiste cristallin. Compte-Rendu Soc. Phys. et d'Hist. Nat., Geneve. Vol. 43, 1926.

Nearer the lower contact the chloritic gneiss contains tourmaline. The feldspar is mainly sericitized and the biotite chloritized. The large feldspars have disappeared. In their place are found larger roundish quartz grains, embedded in a ground mass of sericite and quartz, in a manner comparable to their occurrence within intensely epimetamorphic quartzporphyries. The intergrowth with tourmaline of a pleochroism similar to glaucophane is striking.

The final epimetamorphic product was found in the shape of a layer of 20 centimeters within the lower part of the gneiss in the shape of a dark green chlorite schist, formed by tectonical sliding. Macroscopically this schist is hardly distinguishable from certain Daling schists. The microscope reveals an almost isotropic chlorite of greenish to blue pleochroism. Small individuals of quartz and albite are recognized. Magnetite is abundant, though xenomorphic and of irregular distribution. A surprising fact is the occurrence of sillimanite. The tiny idiomorphic needles are irregularly spread over the rock, and must be regarded as a secondary mineral (Neubildung). A brownish pleochroism is distinctly observed. The occurrence of sillimanite in an epimetamorphic chlorite schist is something unusual. It shows that sillimanite as the stablest mineral form can grow also under pure epimetamorphic conditions in a rock with excessive aluminium contents.

7. Summary

The microscopic research has confirmed the passage of a more or less epimetamorphic zone of argillites (Dalings) via the mesometamorphic garnet-mica schist to the katametamorphic sillimanite gneiss of Darjeeling.

The chemical analyses confirm the supposition that the Darjeeling gneisses are more or less injected rocks of argillaceous origin.

The layers of psammite gneiss and the peculiar inclusions of limesilicates (calcsilicates) are further characteristics of the sedimentary transformation. They are regarded as former calcareous concretionary layers in the clay-slates (Phot. Pl. VIII—IX).

A striking resemblance was established between the Darjeeling gneiss and the Ceneri gneiss of the southern Alpine root zone (BÄCHLIN), both containing the interesting calcsilicate inclusions of the same type and origin.

The gradual upward increase of metamorphism, as already mentioned, suggests a reversed series of a huge recumbent fold. However, it is difficult to conceive a phenomenon of this size, and to imagine the existence of the Daling schists of such little metamorphism in a reversed series. Possibly there are numerous concealed thrust sheets in place of an uniform recumbent anticline, the sum of which assumes the appearance of a reversed series.

In the region of Darjeeling real orthogneisses are unknown. The rocks are paragneisses more or less invaded by magmatic material (migmatite). This injection seems to increase towards the north, as shown by the gneisses of Gangtok which reveal a predominance of orthomaterial. In the Kangchenjunga massive large intrusions of granite and orthogneiss were already recognized (GARWOOD, DYHRENFURTH, AUDEN) increasing towards north.

A similar increase of metamorphism from S to N may also be found in the underlying Dalings, as partly observed on the lower Tista. Such an assumption would justify the above mentioned view of imbricated scale thrusting.

THE LOWER HIMALAYA OF KUMAON

Naini Tal

This beautiful lake 6346' (1935 meters) above sea-level, with its surrounding bungalows and military buildings, is a famous summer resort for the people living in the hot Indian plain.

The geology has been worked out by MIDDLEMISS in 1890 (44). His description begins with the following remarks: "The geology of Naini Tal, in its purer scientific aspects, is neither very attractive nor very instructive". This is as true for the stratigrapher as for the tectonician. Middlemiss' map showing faultlines around the lake, drawn with the ruler in the shape of a cob-web, pointed to the advisability of a revision.

The result of our rapid investigation within a few days showed us first that a larger part of the country than that indicated by MIDDLEMISS is sliding or filled up with blocks of mountain slides, and that even the Ayarpata mountain (7716' = 2350 meters), with its stratified southern limestone face, is generally broken up in such a way that it is impossible to design a correct tectonical section. We even discussed GANSSER's idea whether the whole region SW of the lake had been affected by late-, or post-tectonic sagging, thus causing the breaking-up of the stratification. Although we found some blocks of the „trap dyke" on Ayarpata, neither the intensely folded and faulted Ayarpata syncline of MIDDLEMISS nor the cob-web faults could be verified.

Besides this broken Ayarpata mountain, a large area is covered by what is unquestionably scree material from landslides (Sketch-map Fig. 11). They have broken off from the walls of the crest, extending from China peak (8583' = 2600 meters) towards the south over Deopatha 7987' to the Bajiyun Pass. The structure of this crest is fairly well visible. The unfossiliferous limestones with shaly layers, probably belonging to the Krol series (Fig. 19) as already considered by MEDLICOTT, form the syncline of Deopatha.

The sequence of China peak seems to be cut off by a fault from the main limestone (Krol) series, which is at least 600 and probably over 1000 meters thick.

An interesting exposure of detail at the base of the limestone walls of Ayarpata is passed on the road to Naini Tal below point 6913 (Fig. 18). Possibly the limestone series SW of Naini Tal is repeated by concealed thrust-sheets dipping to the north-east (Plate III, Sect. 6a).

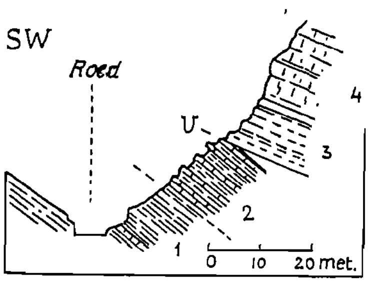

Fig. 18. Basis of the limestone wall of Ayarpata, Naini Tal.

1 = greenish shale with limestone layers

2 = 15 meters of violet clay shale with about 12 beds of greenish dolomite, each 5—30 cm at every 0,5—1 meter. Slight unconformity.

3 = 10 meters of gray shales passing into

4 = about 300 meters of bluish limestones and marls forming the SW wall of Ayarpata:
- a) about 80 meters of blue marls with limestone layers
- b) 50 meters brown weathered limestone
- c) 100 meters thin-bedded bluish limestone
- d) 100 meters of yellowish weathered limestone and dolomite, well-bedded and "banded".

The region SE of Naini Tal is extremely complicated by crushing, crumpling and numerous local faults of different directions. The variegated clay shales with quartzite along the road to Ranikhet (Gainthia and Bhumia Dhar) may partly correspond to the Nagthat series of Tehri Garhwal.

If we try to establish a normal sequence of the formations, we start from China Peak, the snow view point and highest summit of Naini Tal 2600 meters (Fig. 19). There, as already mapped by MIDDLEMISS, a limestone bed is exposed within the shales or slates. It is of a peculiar aspect, made of small lenticular scales of yellow dolomite and bluish gray limestone. Several slices under the microscope showed no trace of micro-organisms.

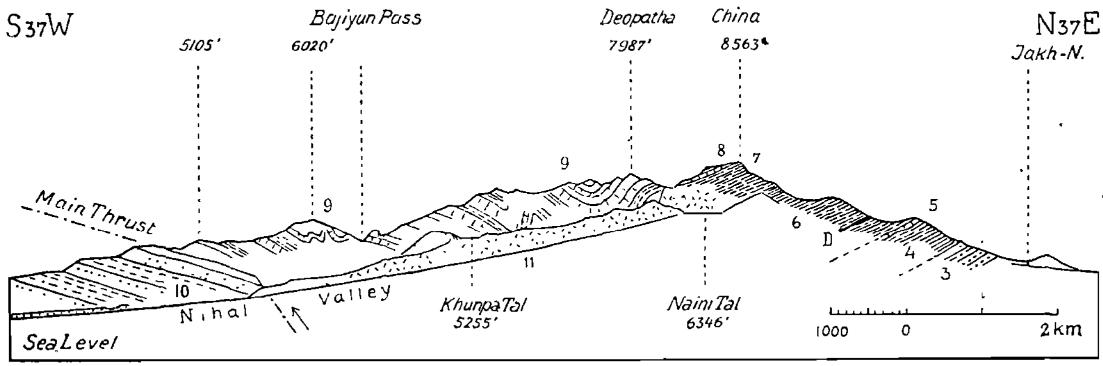

Fig. 19 Section of Naini Tal.

3 = Quartzite; 4 = gray and variegated shales; 5 = gray limestone; 6 = large series of shales or slates, partly calcareous, including a basic sill (D); 7 = limestone layer of China peak; 8 = shales like 6; 9 = thick series of massive limestone with marls (Deopatha—Ayarpata; 10 = middle Siwaliks; sandstones and variegated shales; 11 = scree material of mountain slides, the washed-out material forming the terraces of Nihal Valley (Nr. 3 = ? Nagthat; 4—8 = Infra-Krol; 9 = Krol).

The best stratigraphic series with a regular dip of 25—35° to SW is obliquely traversed from China Peak along the crest to Sherka Danda-Lariakanta.

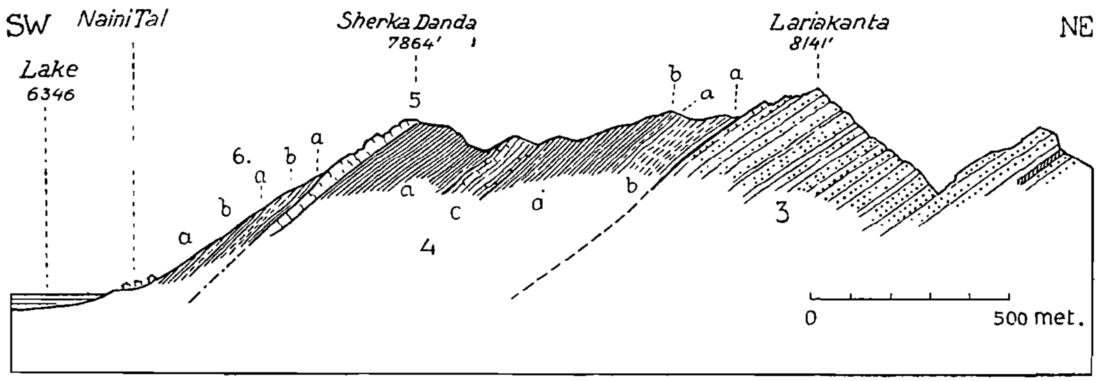

Fig. 20 Section from Naini Tal to Lariakanta (Observation by A. GANSSER).
(Topogr. map 53.0, 1" = 1 mile).

3 = Quartzite, thick-bedded, yellowish to greenish. Sharp limit to 4a = gray clay slates; b = mainly purple slates; c = gray platy shale; 5 = gray limestone with quartz grains, 20 - 40 meters (resembling that of China Peak). 6a = gray slates, b = purple slates. (The numbers 3—6 correspond to Fig. 19).

Interpretation: The first question is, whether we can regard the mighty sequence on the north side of Naini Lake as being one stratigraphic unit. The regularity seems to confirm a normal position, but it may be questioned if the limestone of China Peak No. 7 is a repetition of No. 5 of Sherka Danda. In this case, the series would be repeated above a thrust-plane on the top of No. 5. However that may be, the slaty gray to purple series reminds us of the Lower Krol of the Simla district and Tehri. If so, the quartzite of Lariakanta might correspond to the Nagthat of AUDEN and others. We searched in vain for the Blaini conglomerate above the quartzite.

The formation of the Naini Lake and its neighbours (Bhim Tal) was much discussed already long ago and seems still to be an unsolved problem. While MIDDLEMISS considered a sacking, the depth having been formed when an outlet existed at the bottom across the limestone, which later became closed up, GERLACH postulated a glacial origin and claimed to have established the existence of moraine, not at Naiui Tal but on the corresponding lakes.

Looking around the country from a high point such as China Peak, it seems as if the whole surface of the country as far as Almora were dominated by a dissected peneplain, of an average elevation of 2000—2400 meters. Only the limestone range from China to the NW overtops this peneplain for about 200 meters.

The Transverse Section from Naini Tal to Almora

Following the pretty upper trail through the forest from Naini Tal to Bhowali, we come below the purple and gray shales No. 4 east of the cemetery not directly to the quartzite, but pass a series of carbonaceous slates interbedded with conglomeratic graywacke-sandstone. In vain we hoped to find something determinable of the apparent plant remains. Possibly, this series is Carboniferous.

The quartzite below, gray and variegated, may be 500 meters thick and seems to correspond to the Nagthat.

So far, the dip was towards WSW. But at the Sanitarium above Bhowali a sudden change occurs. Steeply erected and crushed rocks follow, consisting of quartz-conglomerate, green amygdaloidal diabase with vesicles of epidote and calcite, intersected with quartzite and crushed slate. Good exposures are found on the motor road at Bhowali (Pl. III).

On the slope opposite Bhowali, green rocks are exposed over another kilometer. It is true that they are more slaty and interbedded with quartzite layers and dolomite. No repetition of the sedimentary series of Naini Tal being found, we conclude that this series of green rocks is older than what has been found further SW, and older than Carboniferous.

The green schists (Grünschiefer) of Bhowali form the bases of a huge series of formations which, as far as Almora, dip with more or less regularity towards NE.

Along the trail from Bhowali via Ramgarh we encountered the following main subdivisions from below (Pl. III):

	approximate thickness (meters)
1. green schists with quartzite and dolomite of Bhowali	1000
2. quartzite, dipping 30°—40° NE	500
3. quartz porphyry of Ramgarh; mainly slaty, but partly porphyritic or gneissic, with minor intercalations of phyllite (Benaik pass); average dip 30°—35° to NE	2800
4. quartzite of Ram Gad bridge, dip 50° NE	700
5. amphibolite with basal layer of quartz porphyry, strongly stretched, containing iron-manganese ore (abandoned high furnace)	30—50

6.	quartzite and sericitic phyllite with manifold repetitions and an amphibolitic layer in the middle part, dips diminishing from 50°—30°	1400
7.	dolomite and limestone with slaty layers in the lower part, well bedded, with massive marble on the top, dipping 35°—40° NE, passage into Nr. 8 .	500
8.	sericite phyllite (schistes lustrés) with quartzite layers in repetition (passing to No. 9)	500—800
9.	sericite-schist with increasing metamorphism upwards, garnetiferous at bungalow of Peora. No. 8—9 recalling Daling series (passage to Nr. 10) . .	1600
10.	mica schist, partly gneissic, with garnet; average dip 30° to E and ENE (passage to Nr. 11)	1200
11.	muscovite-gneiss with little biotite (forming the Kali Rau gorge above Gurari-bridge)[1]	1200
12.	mica schist with quartzite layers overlie the gneiss W of Dyoli, dip 30° to NE. Garnets in lower part	200
13.	Almora-granite with biotite, massive intrusion, gray, partly gneissic, coarse-grained	1000
14.	The gneissic top of the granite is overlain by mica schist with thin-bedded quartzite layers, dip 30° to NE.	60
15.	mica schists, with garnet in lower part	200
16.	sericite schists and mica schists with quartzite layers: series of Almora	1500
		14700

Interpretation

The above series from Bhowali to Almora, about 15 kilometers in thickness, seems to be reversed in its north-eastern part. Indeed, from the Nathua Khan pass to the Kali Rau gorge, the metamorphism gradually increases upward and this not only apart from the granite intrusion.

On the other hand, the sedimentary series of the Ram Gad valley with its regular stratification shows all the aspects of a normal series. Possibly the tectonical position of Nathua Khan is that of a recumbent syncline. The series is intensely stretched. Beautiful slickensides in the direction of the north-eastern dip were encountered on the surface of a quartzite layer SW of Nathua Khan. However, no signs of a major thrust-fault were found.

Some Observations at Ranikhet

The outcrops along the motor road from Ranikhet to Almora with its great turn oblique to the strike of the formations do not make it suitable for obtaining a clear view of the structure and were not studied properly. Some outcrops, howewer, are remarkable.

Coming to the bridge over the Kosi, at 29° 30' of lat., the greenish shales and quartzites, representing possibly the Nagthat series, seem to be overlain by a vastly extended series of sericiteschists with layers of quartzite which dip 30—40° to NE and NNE. The road is cut out of these schists for 10 kilometers, as far as below Chaubattia, where they become more metamorphosed in the shape of mica schists with small garnets, dipping 20° to NNE (thickness 200—300 meters). They are partly well stratified and contain thin layers which may be called psammite gneiss. Above them, at Chaubattia-West, there is a large wall of gneiss, partly broken down in the shape of a mountain slide. It is a real ortho-gneiss with augen up to 2 cm, and of about 50 meters thickness. Fresh specimens can be taken from a quarry.

[1] South of the Kali Rau river the trail deviates 2½ miles to the SE of the section line of Pl. III. The outcrops of the trail have been projected into the section line; thus the section cannot be quite accurate.

This gneiss supports nearly horizontally another series of mica schists extending to the post office of Ranikhet which again is situated on intrusive gneiss. Many of the pretty bungalows and gardens are built on white, deeply weathered granite-gneiss, upon which extend again the mica schists with subordinate quartzites and carbonaceous shales, as far as Almora.

The gneiss of Ranikhet corresponds tectonically to the granite of Almora which is more massive, partly on account of its much greater thickness. At Ranikhet, as well as SW of Almora, the upwards progressive metamorphism is considered as a reversed stratigraphic series.

Beautiful *river terraces* are cut out along the Kuch Gad as seen from the motor road to Ranikhet. They are deserving of a special study. One of the most prominent is that of the farm houses of Chapar (map 53^{0}_{0}, 1″ = 1 mile) at 3800—3900, 1000′ above the river.

The Region from Almora to Askot (A. GANSSER)

East of the Nanda Devi Temple at Almora, along the steep slope towards the Sual River is situated a large quarry where the slabs for paving and roofing are extracted. Beautiful even slabs of the size of several square meters can be taken out, each 1 – 10 cm in thickness, representing one bed of original sand deposit, transformed into very hard quartzite, which is interbedded with argillaceous layers now in the state of mica schists. On these slabs the evidence of mechanical stress caused by differential movement is given by the linear disposition of the mica flakes. Their disposition is usually in the direction of the main movement to SSW, but at a small quarry 2.5 km north of the Mission hill, *longitudinal* stretching in EW direction was found. On the deeply weathered surface, as for instance in Almora town, the mica schist looks like a Tertiary to recent deposit of sand and clay recalling Molasse sandstone or Nahan-Swaliks. This was their original facies.

Following the trail via Chitai and Bari Chhina to Kanari Chhina, the following structure is encountered (Fig. 21):

First the mica schists of Almora (frequently with garnet) continue their gently undulating north-eastern dip, partly altered by transverse warping. The trail glitters in the sun as a consequence of reflection from the mica scales.

Descending to the Mahadeo creek, two lenticular orthogneiss intercalations are found within the garnetiferous schist, and also a first indication of *black carbonaceous* shales. They are interbedded throughout a zone of 100 meters with thin layers of sericite-quartzite.

On the north side of the little bridge the aspect is altogether different. Black carbonaceous shales, staining the hands like graphite, follow the foot of the mountain 5111′ (map 53^{0}_{10} 1″ = 1 mile) with a gentle north-eastern dip of 15 – 25°. The lower of the two carbonaceous bands is about 50 meters thick and recognizable on a long distance. Above it follow again mica schist and quartzite, then the upper black subdivision.

The overlying mica schist series forms an unsymmetrical *syncline* at Bari Chhina. The trail passes over the northern limb where the carbonaceous series reappears with a 75° steep southern dip.

The carbonaceous beds within the extensive series of mica schists seem to be useful as a mapping horizon. They reappear on the trail from Almora to Binsar (Pl. II Sect. 6b), then cross the Nana Kosi valley with a pitch of 20—30° to NW and are also traversed on the motor road W of Koirali, below point 5491′.

On the south-western slope of Dhaul Chhina Pass, at least 7 intrusive bodies of granite-gneiss with feldspar-augen appear reaching 70 meters in thickness. In some cases the sharp steep contact is at an angle of 20 – 30° with the less steeply inclined mica schists. The top of the pass (1830 meters) is also formed of white lenticular granite-gneiss.

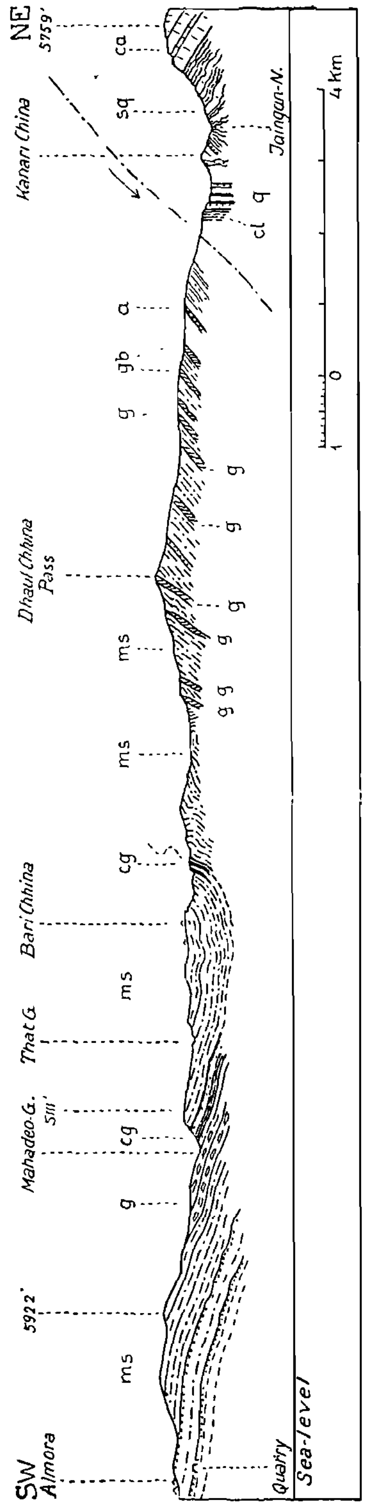

Fig. 21 The Transverse Section Almora-Kanari Chhina

ms = Mica schist with quartzite layers; g = orthogneiss, Augengneiss; cg = graphitoid layers; gb = basic greenish gneiss; a = amphibolite; cl = chlorite schists (altered amphibolite); q = sericitic quartzite; sq = slate and quartzite; ca = *limestone*, partly dolomitic (= Krol?).

The adjoining mica schists are usually more garnetiferous than those farther away from the intrusions.

A further gneiss outcrop is crossed on the trail down to Kanari Chhina. Compared with the southern gneiss, it seems to be somewhat more basic, porphyritic. Then follow within the regularly 40°—50° SW dipping sericite schists several greenish gneiss-like and quartzitic zones with some white feldspars, and a green amphibolite, about 30 meters thick. The contacts of the latter with the schists are sharp. The last gneiss-like rocks of 10—30 meters, of hyperacid appearance, are at Naugaon, together with chloritic phyllite.

Outcrops are lacking for several hundred mèters, just there where a great thrust plane is expected.

SW of the Forest Bungalow of Kanari Chhina, a thick series of vertical sericite quartzites with westerly strike is exposed, probably belonging to the sedimentary series below the supposed thrust plane.

Below the bungalow, a few steps south of the bridge over the Jaingan river, the quartzite-slate series dips to SSW. In the river bed itself the strongly contorted slates with quartzites are practically vertical. The same series, a little north of the bridge, dips 45° to NE.

The higher cliffs of the northern slope are made of fine-grained to dense dark limestone, with flint concretions recalling Krol limestone. Microscopic examination proved this limestone to be entirely devoid of organic remains, even where the original dense structure is preserved. The strike is W to WNW.

The river follows a more or less vertical zone. At the village of Badolisera, where the Jaingan joins the Sarju, the structure of Kanari Chhina is clearly exposed again. The right bank of the Sarju, near the hanging bridge, shows continuous outcrops from the southern dip over the vertical to the northerly dipping zone (Fig. 22).

The peculiar fan-like anticline of Kanari Chhina and Badolisera recalls somewhat the northern Tertiary anticline of the molasse in Switzerland where also the two limbs do not correspond to each other.

Towards north a mighty repetition of limestone and quartzite is traversed. It forms the long ridge towards WNW, between the Jaingan and the Sarju River.

The southern crystalline zone of Almora is thus weathered away to the north and above the anticlinal sedimentary zone. The latter, with its fan opened

downwards may be called the zone of Badolisera. We subsequently found it again further west at Takula.

The limestone series is about 500 meters thick. From below (south) the passage is gradual. The quartzite intercalations of the slate series (2 of Fig. 22) become thinner (about 1 meter each). Then follows a zone about 100 meters thick with the first limestone layers in the slate. They gradually increase until we come at once to the main body of limestone. Closely examined,

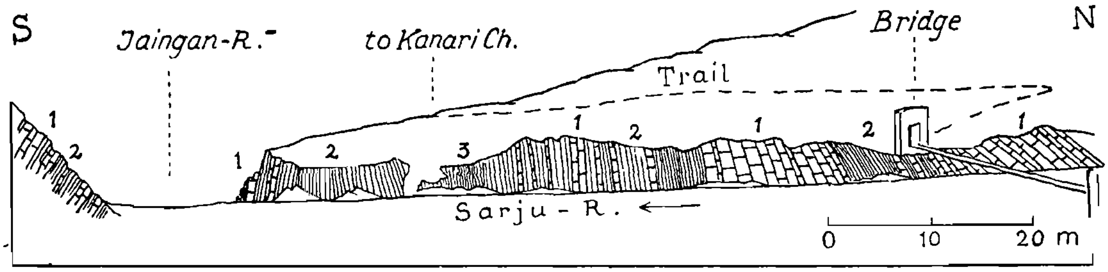

Fig. 22. The Vertical Zone of Badolisera.
1 = Quartzite; 2 = slate: 3 = greenish and reddish slates, partly disturbed.

it shows a finely stratified repetition of limestone and dolomite showing little or no metamorphism. The banding of white and gray layers corresponds to the more or less dolomitic character of the primary deposition. In some zones the fine bands are folded.

The whole limestone series dips about 60° to 70° towards north. On its north side follows quartzite again, with the same strike, but folded to a vertical position.

The trail to Ganai now leaves the Sarju valley and ascends towards the pass of Phadiari, crossing two further zones of limestone. They also lean towards quartzite and slate. The northern dip gradually turns towards 50° to NE.

The two limestones mentioned above, and the southern one especially, are surprisingly rich in barytes of coarse, crystalline to breccious structure, partly intersected with talcose layers. The barytes zone has a thickness of about 200 meters. On its south side, between it and the quartzite, a small intercalation of amphibolite was found.

At a short distance this side of the pass at Phadiari, the quartzites are interbedded with green sericite-chlorite schists up to 50 meters each, of the Daling type. Also one mile west of Ganai such greenish sericite schists occur. The previously prevalent regional dip to the N or NE is no longer pronounced. The quartzite, as well as the limestone on its south side, are locally crumpled (Fig. 23).

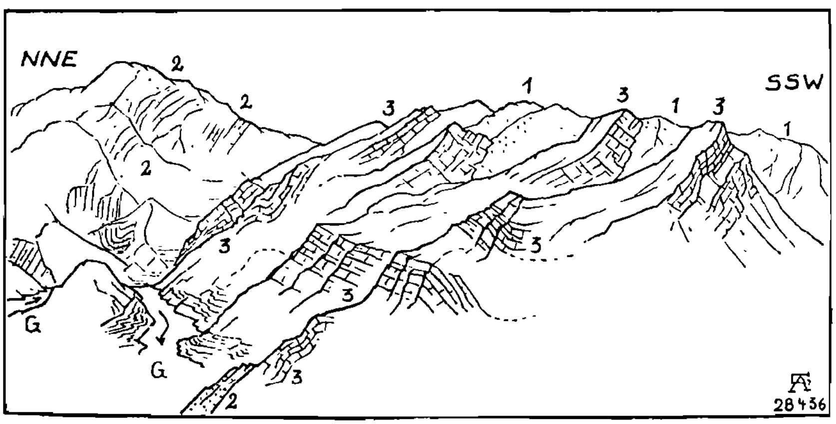

Fig. 23. View from the Forest Bungalow of Ganai towards Godi Gad (G).
1 = White quartzite,
2 = gray and yellowish quartzite,
3 = dolomitic limestone.

North-east of Ganai, a vast zone of quartzite is traversed. It is very thick-bedded and in places shows small pebble-layers, chiefly of quartzite. This and the frequent quartz veins recall the aspect of the "Tal quartzite", as recognized in Garhwal by J. B. AUDEN. The underlying limestone which may correspond to the Krol series points to this conception too.

South of Jakheri, the quartzites are again interbedded with Daling-like schists. The tectonic position becomes more complicated, the dip being now abnormally 30° to SW.

At Jakheri the quartzite is overlain by slate, below which appears a bed of limestone. Its dip of about 50° towards SSW is normal again. The local conditions are shown in Fig. 24.

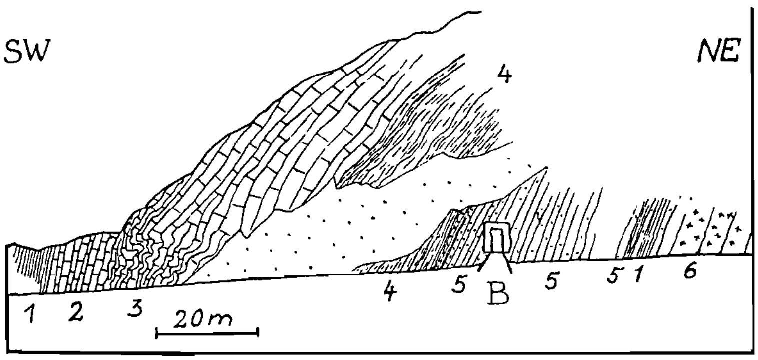

Fig. 24. The Limestone Zone of Jakheri
1 = slates; 2 = minutely banded limestone and dolomite; 3 = banded limestone, intensely folded; 4 = sericite schists of silky luster with intercalations of less metamorphic slates; 5 = well-bedded quartzite with sharp contact towards the slates; 6 = dioritic-amphibolitic sill; B = bridge over the Godi Gad east of Jakheri.

The quartzite to the south of the limestone is partly conglomeratic. The pebbles of quartzite are as much as 25 cm in diameter. Even the nonconglomeratic part is coarse-grained. The limestone is nonmetamorphic, bluish gray, and interbedded with fine dolomitic layers.

The sericite schists below the limestone are intensely folded. They also contain layers of less metamorphosed slates. The limit towards the quartzite on the north side is made of a twofold change of slate and quartzite, of 10 centimeters each, and thus is well defined. A dioritic sill is exposed over a width of about 20 meters, but may be much thicker.

The succeeding zone of quartzite is at least 3 kilometers wide. It is cut across by the Godi Gad. The strike remains little changed, whereas the dip changes to 30—40° towards the NE.

This change in the direction of the dip is not noticed in the wide valley flat of Bans. Probably there is a large, though complex anticline. That the large quartzite body does not represent the primary thickness is shown by the frequent complications in the Godi Gorge (Fig. 25), as well as by the intercalated sericitic slates.

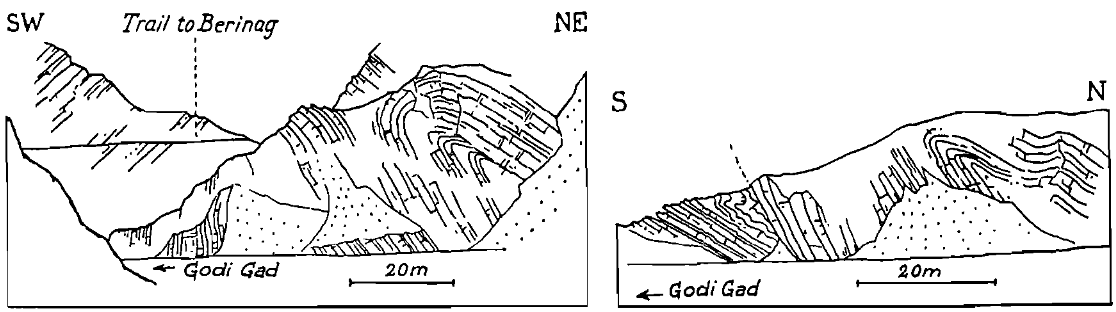

Fig. 25 (A and B) Folded and locally thrusted quartzites in the Godi Gorge.
A The axis of the anticline striking W30N
B The axis and the thrust line striking W.

Besides the folding, we frequently come across local shearing thrusts. About 3 kilometers east of Bans, a fairly large limestone zone is encountered. With its strongly folded, well-bedded layers it quite resembles the limestone zone south of Bans. The normal dip to NE (40°) suggests a connection with the limestones of Jakheri, all the more so as the underlying slaty layers seem to form a complex anticline.

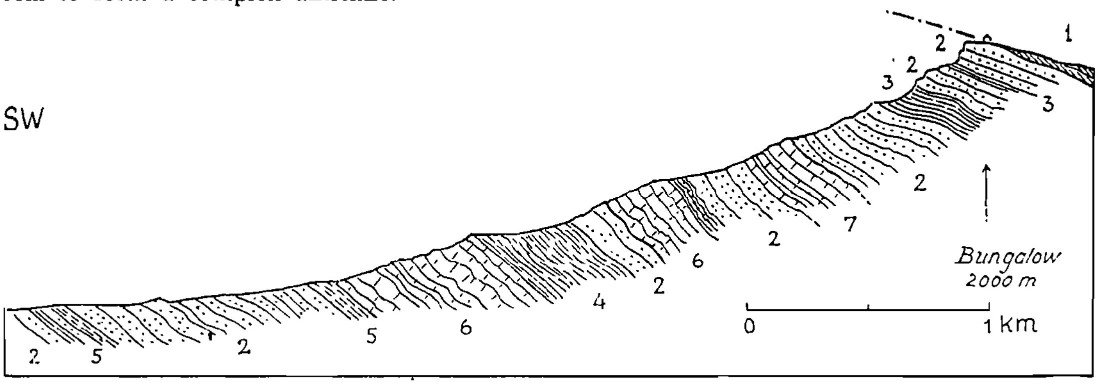

Fig. 26. Section of Berinag.
1 = gneiss; 2 = quartzite and sericite-quartzite; 3 = sericite schist; 4 = Daling-like schists; 5 = shales or schists, more or less sericitic; 6 = limestone; 7 = dolomitic limestone.

The steep ascent to Berinag across the strike reveals an interesting section (Fig. 26). After the limestone follow greenish sericite-chlorite schists of the Daling type. Then comes a small zone of quartzite and another limestone, the intense deformation with cracks and veins of which are suggesting a stronger tectonical influence. It again borders on a light gray quartzite which on the contact is slaty and sericitic.

The uppermost limestone above the quartzite zone is fine-grained and weathers to a somewhat yellowish colour. The slight reaction with HCl points to dolomite.

The following sericite quartzite with its interbedded sericite schists form the walls below the Forest bungalow of Berinag. There, the slaty quartzite layers are nearly horizontal.

The quartzite zone of Berinag is overlain by gneiss with highly metamorphic sericite- and sericitic chlorite schists. The contact below the gneiss (partly ortho-gneiss) is not exposed. Sericite schists seem to follow the boundary.

South of Girtia, the first mighty body of gneiss is overlain by sericite schists with a rather massive amphibolite of about 10 meters. Its contact to the schists is sharp. The sill dips 30° to N.

Further basic intrusions, usually weathered, are encountered at Chanpata. They may be in connection with the sill of Girtia.

Descending farther towards Tal on the Ramganga, the strike changes several times. In places, vertical gneisses are encountered, the strike of which deviates from E to NE. Shortly before Tal a further amphibolitic sill is crossed, while at this village itself a fairly regional though abnormal NNE strike was observed. The gneisses dip to ESE and are overlain by black argillaceous slates. On the left bank of the Ramganga we unexpectedly met with a banded limestone layer of 1—2 meters, discordantly superposed by quartzite (Fig. 27). The dip is 70° to ESE. The quartzite is again overlain by sericite schists. Above it follows muscovite-augen gneiss with tourmaline. Unfortunately the contact here also is not properly exposed.

Up to an elevation of 5610 the zig-zag trail mainly traverses gneiss. The latter is very acid in the lower part, with muscovite and locally much tourmaline. Upwards more biotite occurs, while tourmaline disappears. The gneiss first dips 30° to E. Dioritic sills of 5—10 meters or below are intercalated within the sericite schists.

About 3 kilometers east of Thal, the eastern dip passes into a southern dip. On the saddle about 2 kilometers west of Sandeh, a reddish weathered dioritic sill is exposed, 100—150 meters

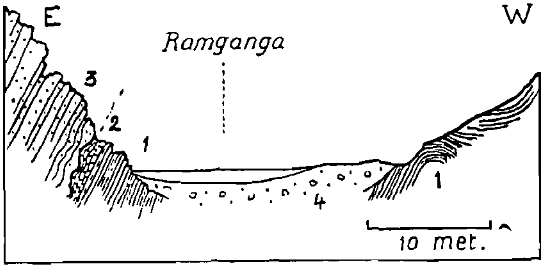

Fig. 27. Detail of the Ramganga at Thal.
1 = Black shales or slates; 4 = River deposits.
2 = Banded limestone;
3 = Quartzite;

in thickness. Corresponding rocks were found before as pebbles in the Ramganga. We therefore conclude that these basic rocks are also widely distributed towards the North.

Overlying the diorite are garnetiferous phyllites, frequently folded or crumpled. They in turn are superposed to the south by a coarse, somewhat lenticular gneiss which forms the entire Dechula mountain (Point 7656').

As far as Askot the trail follows the northern rim of this vast gneiss thrust. To the North of the Forest Bungalow of Sandeh, the normal south-eastern strike is restored, usually with a steep south-western dip below the gneiss and the sericite schists. The bungalow is situated on the garnetiferous phyllite with its basic dykes. The latter no longer resemble the more dioritic types found within the underlying sedimentary series, and they also show much stronger tectonical influence. This occurrence of Sandeh is not in the shape of a sill, but of a true dyke crossing the garnetiferous schists as well as the overlying gneiss.

Very suggestive outcrops are presented by the rocky crest upon which is situated the small temple of Sirakot (Fig 28).

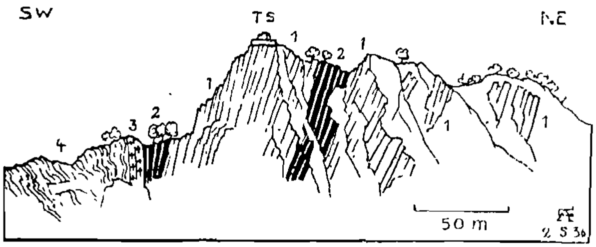

Fig. 28. The rocky ridge of Sirakot northeast of Sandeh.
1 = Well-bedded yellowish quartzite;
2 = Schisty amphibolite sills;
3 = Schistose gneiss;
4 = Sericite schists, partly with garnet, partly with chloritoid;
TS Temple of Sirakot.

Below the garnetiferous sericite schists are strongly compressed amphibolite sills. They in turn overlie a large sèries of well-bedded quartzite. The latter, however, are not uniform, but again contain a basic dyke. All formations are steeply inclined, dipping to one or the other side of the vertical.

Similar structures occur all along from Sirakot towards SW via Askot and beyond the Nepal boundary. A fact of special interest is the intercalation of basic rocks along the boundary of the quartzite and the crystalline series. Similar basic (usually dioritic) conformable intercalations were found by the authors along most of the gneiss thrusts of the Central Himalaya between quartzite and the overlying gneiss and mica schists.

North of the zone of Sandeh-Askot a regional NW strike is seen at a long distance. The trail to Askot follows the gneiss. Only east of Dindihat it passes over the northern rim of the Askot Thrust. There, as at Sandeh, it is formed of garnet-sericite schists. Only the quartzites, which here too are separated from the crystalline series by amphibolite, show a steep dip below the gneiss.

Towards Askot the texture of the gneiss becomes more porphyritic, with feldspar augen. Tourmaline is constantly present in fine idiomorphic needles. The village lies on sericite schists with two large bodies of amphibolite (Forest Bungalow of Askot).

In order to find the contact to the augengneiss again, one has to follow 1—2 km along the trail towards Pitoragarh. The two amphibolites on the south side of the Forest Bungalow of Askot are overlain by quartzite which forms a gentle syncline, followed by a gentle anticline. The latter, at the little post office of Askot, is again overlain by amphibolite with a southern dip. Three further zones of amphibolite separated by sericite schists were found. The latter are locally vertical and form the boundary to the granite-gneiss with its S to SW dip.

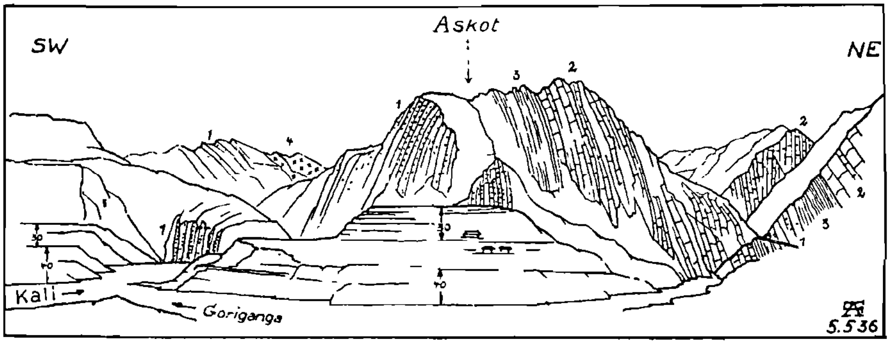

Fig. 29. View of the ridge southeast of Askot.
1 = Quartzite; 2 = limestone; 3 = slates and schists; 4 = gneiss of Askot

The gentle folds of quartzite mentioned above pitch towards W below the gneiss sheet. This gneiss, here too, is very coarse, the eyes of feldspar attaining a diameter of 5 centimeters.

In conclusion: The structure of Askot suggests a great thrust of gneiss coming from the NE. Probably the gneiss sheet extends towards west as far as Berinag, where it is doubled, as indicated by the complications of Thal. The conditions east of Askot, in the gorge of the Kali, with its huge limestone-slate and quartzite series point even more decidedly to the conception of thrusting. This sedimentary series recalls in fact that of the Godi Gad, west of Berinag (which also plunges below the gneiss), and also those of Badolisera. Finally, the occurrence of barytes about 1,5 km below Balwakot on the Kali points to the above tectonical coordinations, as they are exactly of the type of those at Badolisera.

The huge crystalline sheet of Almora ends as a result of erosion at Kanari Chhina and is underlain by the very complicated anticlinal sedimentary Zone of Badolisera, with its inversed fan structure. North of it follow several non-metamorphosed or slightly metamorphosed zones of limestone with mighty quartzites above. South of Bans these limestones, reduced to one, reappear in the shape of a complex anticline with a quartzite core, while SW of Berinag they again dip below quartzite, forming three different zones. From Berinag there is an extension of the gneiss towards the east, which is probably a continuation of the crystalline Almora-Kanari Sheet.

The Transverse Section of the Kali along Nepal

(Pl. II, Sect. 4)

a) Tectonics

Descending from the village of Ascot (1400 meters) to the Gorge of the Gori Ganga (600 meters), a complicated and crumpled zone is traversed below the steeply inclined mica schists

made of amphibolite, quartzite with interbedded chlorite schists and sericite schists with quartzite layers.

Then follows a huge vertical series of banded crystalline limestone with interbedded black slates and sericite schists at a regular strike of W 30—40° N, showing less metamorphism. It is traversed along the trail which follows the west side of the Kali gorge above the Nepal bridge point 1967' (map $62\frac{C}{NW}$, I" = 2 miles).

After the massive limestone walls, the series becomes more argillaceous. Layers of calcareous sandstone are interbedded with phyllite, recalling the Alpine "schistes lustrés" (dip 50° to SW).

The surroundings of Balwakot are wanting in clear outcrops. At the place + of Pl. II sect. 4a we found loose blocks of barytes breccia similar to that north of Badolisera. Above this miserable village, the Kali river flows westward for 5 kilometers through an anticlinal limestone gorge of corresponding deviation in the strike. On the SW-NE section of Pl. II it could only be indicated approximately.

The prominent point 4496' above the mouth of Ghat Gad 2460' is in the position of a narrow syncline of limestones and dolomites with a WNW strike and dips of 70—80°.

On the Nepali side of the Kali river, opposite Galanti, the limestone and dolomite form high mountains with an anticlinal structure, but again with an abnormal ENE strike. At Darchula, the folding of the calcareous series with phyllites is more irregular and the section 4a can only give an approximate idea of the structure. However, 3 miles NE of this village, the limestone and dolomite clearly dip to the NNE again with angles of 30—45°. Then comes a sudden change, for, after an intermediate layer of phyllite, we suddenly reach a gorge of gneiss dipping gently to the NNE. Unquestionably we stand before a great overthrust coming from the N. As seen at a distance, the mountain to the west seems to be crowned by white quartzite of an intermediate position.

The trail gradually rises above the river as far as Khela, over nearly flat biotite gneiss, recalling that of Darjeeling. It contains a zone of interbedded sericite phyllite, a band of chlorite schist and amphibolite, with sericitic quartz porphyry, in the shape of slate above it. The dip is 25° to N 30E.

The tiny village of Khela is partly hidden in gneiss blocks of a landslide.

North of Khela, the trail crosses the Dhauli gorge, then again rises steeply above the gneiss, up to 1950 meters. The latter is gradually replaced by chlorite-sericite schists of over 1 km thickness.

The next surprise is a most remarkable ortho-augen-gneiss just above the pretty village of Panghu. It forms a mountain slide of big blocks. The feldspar augen reach the amazing size of 10—16 centimeters in length. The gneiss of Panghu has a thickness of about 300 meters. Above it, dipping 35—40° NE follow some mica schists, then about 250 meters of quartzite, covered by amphibolite.

On the opposite eastern side of the Panghu Valley the intrusive granite-gneiss disappears. The picturesque village of Soso on the mountain crest is situated on sericite schist, above which follow quartzite and amphibolite crowned by a vast series of calcareous phyllite (Alpine type of "Bündnerschiefer") (Fig. 30).

The quartz phyllite forms the top of a hill above Sirdang of 3100 meters, presenting a beautiful view all round. Towards west the regional steepening dip towards north of the gneiss and its overlying series is visible for a long distance, while the view down to the imposing Kali gorge to the east also reveals an astonishing regularity of the structure on a large scale, namely a general dip of the quartzite-amphibolite-phyllite series of 45° to N25E (Fig. 60—61).

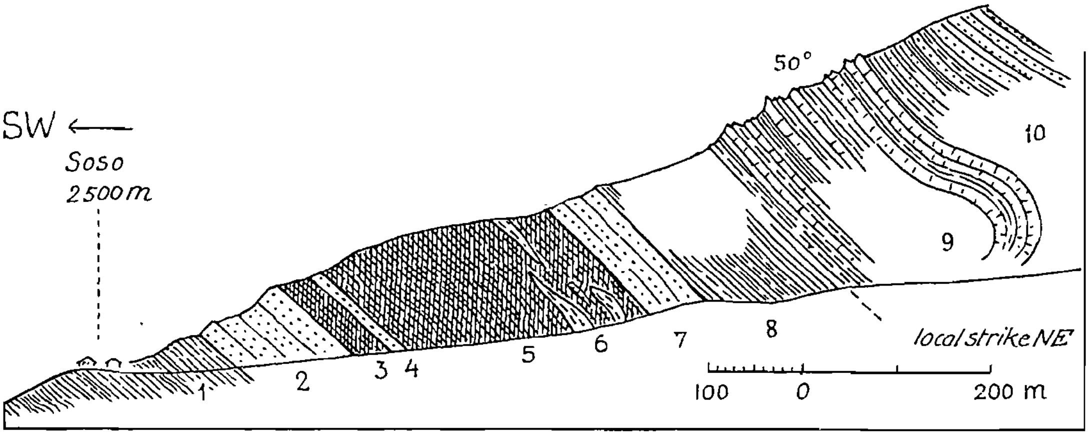

Fig. 30. The semi-metamorphic series of Soso.
1 = Sericite and chlorite schist; 2 = white quartzite with sharp boundaries, about 100 meters; 3 = amphibolite, 30 meters; 4 = quartzite, 10 meters, sharply defined; 5 = green amphibolitic series, with 6 = lenticular inclusions of chlorite schist and quartzite; 7 = quartzite 50 meters; 8 = sericite-chlorite-phyllite, calcareous, passing into 9 = calcphyllite; 10 = quartz phyllite.

Apparently we are in a normally ascending series, the metamorphism of which, as a whole, is decreasing. NE of Sirdang village, the trail crosses within the phyllite zone a 20 meter layer of coarse-grained marble, then a spotted limestone lense. The first one might be a transformed echinoderm breccia, the second an altered coral limestone. But only several hundred meters further follows the main limestone series: 150—200 meters of partly sandy marble of brown weathering, locally rose-coloured, well stratified, and still dipping 45° NE.

We are now at the upper end of a wild gorge of a side river flowing SE to the Kali. The trail enters the upper part leading through a forest of wild chestnut trees and oaks up to the Dharma pass, an altitude of nearly 3000 meters. With an unchanged dip the following series is traversed above the limestone (Pl. II, sect. 4a):

1. Phyllite, about 200 meters
2. amphibolite, schistose, 30—40 meters
3. micaceous quartzite, well-bedded, 300—400 meters
4. amphibolite, partly covered, ? 20 meters
5. gneiss with muscovite and biotite of Darjeeling type.

Obviously, this second gneiss series is thrust again over the sedimentary group, the dip of the thrust plane being 45—50° to NNE.

It is this Darjeeling gneiss which forms the beautiful oak forest of the Dharma Pass. Minor basic (amphibolitic) intrusions and a dyke or sill of greisen-granite were noted, the latter just on the top of the pass. The thickness of the gneiss is about 2500 meters.

The descending trail passes a vast block region of an old mountainslide of gneiss from the west.

At Shankula camping ground (2200 meters) and thence to the bend of the trail below point 11257′, the "Zweiglimmer-gneiss" is overlain by a zone of psammite gneiss and of mica schist with garnet and staurolite of some hundred meters, including a basic sill. Then follows a zone of augengneiss with very large feldspar-augen repeated several times, subdivided by quartzite, the thickest of the gneiss sills measuring about 20 meters.

The succeeding series of 2000 meters thickness is of sedimentary origin and changes frequently from quartzite to psammite-gneiss and mica schist containing mainly biotite, garnet and tourmaline. The dip increases to 60° and in places to 70° to NE or NNE.

Coming to the waterfall of Nayan Gadh, we met with the first true igneous dykes of pegmatite, which cross the metamorphic strata. The latter are mainly quartzite, sericite-quartzite and mica schists in repetition, and frequently contain kyanite. Near Malpa they become intensely folded (Fig. 62).

At the camping ground of Malpa a quartzite of about 250—300 meters thickness forms huge walls. There, the surface of a bedding plane in the upper part shows beautiful striation of tectonical friction in the dip 45° to NE, on a gigantic scale.

Further NE of Malpa, the rock may be called an injection gneiss, and partly is a real augengneiss with large feldspar-eyes, also containing sills and dykes of pegmatite (progressive contact metamorphism upwards).

Above the gneiss, a beautiful parabolic syncline is visible on the W side of the trail, made of well stratified psammitic gneiss and mica schists (photo 12, Pl. IX). Another similar fold follows at less than one kilometer distance. (Pl. II, section 6b.) There, the whole series of metamorphic sediments (psammitic gneiss and calcsilicate schists) is traversed and penetrated by swarms of dykes, chiefly of pegmatite and granite. They are younger than part of the folding, cutting and crossing the latter independently. They are also younger than the intrusive augengneisses. It is mineralogically the most interesting zone of the whole traverse of the Himalaya along the border of Nepal (see petrologic description).

Below Budhi, the granite forms large dykes, attaining thicknesses up to 50 meters. But above this village the injections come to an end, and we are apparently at the basis of the huge sedimentary series, equivalent to the Haimanta system of GRIESBACH and HAYDEN, and regarded as Algonkian to Cambrian. It continues to Garbyang and will be described in a later stratigraphic chapter. It only need to be mentioned here that at Budhi village, where the pegmatite dykes are dying out, the basis of the phyllite series still shows a characteristic minute feature of metamorphism: the sericite schists contain tabular to almost cubic porphyroblasts of biotite, and streaks of marble.

b) Morphological Features—Moraines

The old river terraces would be worth a special study, for which our limited time was insufficient. Moreover, the Nepalese side, where the finest terraces are seen, was inaccessible.

A gravel terrace about 40 meters above the Kali was met with at the mouth of the Gori Ganga (Fig. 29).

A most interesting region of terraces along the Kali is that of Balwakot. At the northern river bend, south of point 4111′ (map $62\frac{C}{NW}$), the lower gravel terraces are cut off in the shape of walls, one about 15 meters, the other about 60 meters above the river. An even higher flat on this Nepal side is estimated at nearly 300 meters above the river.

The gravel terrace above Darchula seems to correspond to the lower one of Balwakat. If this is the case, the slope of these younger terraces would conform to that of the actual river bed.

Between these river sections where the valley widens and the current is normal, there are rocky gorges: first from Askot is seen the Gori Ganga with its convex slopes The Kali, above the confluence, crosses the vertical limestone barrier in the shape of a gorge. Another narrow is that through the deviated anticline below Ghat Gad.. Above Darchula, through the thrusted gneiss, the river has cut out a long gorge, again with characteristic convex slopes (Fig. 31).

Above the mouth of Dhauli Ganga, the trail for a two days' journey turns away from the valley, its gorge being inaccessible. The grade of the current here becomes so steep that no more fish are found above Darchula. A magnificent view down the valley to the SW is obtained on the knee of the trail below point 11257'. Again the slopes are convex, proving accelerated erosion up to the present time (Phot. 13, Pl. IX).

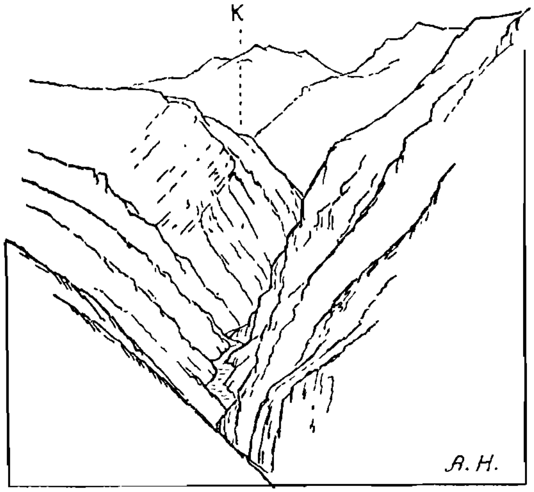

Fig. 31. The gorge of the Kali through the gneiss above Darchula, looking North. K = position of Khela.

A new morphologic feature is encountered about a kilometer above Malpa. The trail is cut through the terminal moraine of the last glaciation (Würm?) at 2160 meters (barometric). One hundred meters higher, striated quartzite pebbles were collected in loam of ground moraine, mixed with steeply inclined, sandy clay, probably a shifted lake deposit. (Photo 14, Pl. IX). The river here seems for some distance to have deviated from its former course, cutting a deep gorge into the gneiss (Fig. 32).

Further upward the glacial deposits are interrupted by ravines and partly washed down. Where they have remained, a new feature is visible on the Nepali side: the moraine is covered by sandy clay with varves (at an altitude of 2270—2320 meters) upon which are remains of a fluvioglacial gravel terrace. The sandy clay is partly horizontal, partly slightly inclined, and at some places dislocated by slipping or glacier movement to an almost vertical position.

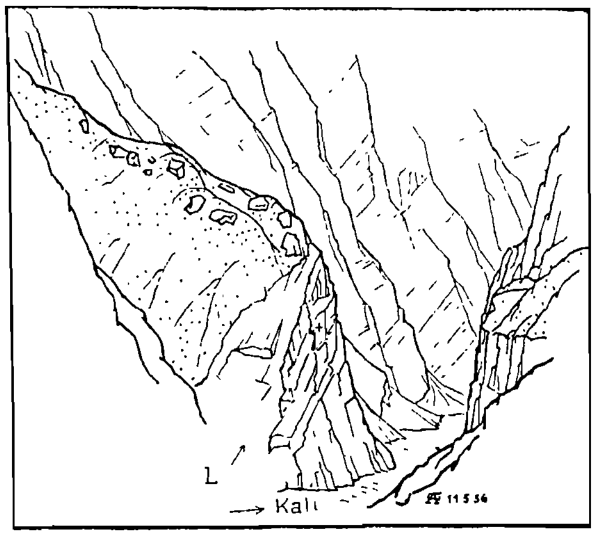

Fig. 32. Epigenetic gorge of the Kali above Malpa. Points = moraine; L at + = Lammergeier nest.

About 2 kilometers SW of Budhi the trail climbs over a moraine wall of a first stage of recession. Its top is at an altitude of 2680 meters (barometric), about 150 meters above the river and about 5 kilometers behind the terminal moraine. The fluvio-glacial gravels further down the valley have probably been washed out of this moraine.

Behind this wall and below Budhi a dissected fluvioglacial terrace of gravel extends along the river.

SE of Budhi is the deposit of a large subrecent landslide which came down from the walls in the SE (Fig. 46).

The Transverse Section from Almora to the Sarju River (Pl. III, Section 6b)

The first part of this section is similar to that of the Chhina's (Fig. 21). The trail first leads over the wooded ridge of Kalimat (6412') where at a mile distance north of Almora the

carbonaceous shale series is crossed. On our north-eastern section the stratification appears to be practically horizontal, the dip or pitch being slightly towards east.

On the NW side of the saddle Kapar Khan continues the syncline of Bari Chhina. The carbonaceous series, here too, is interbedded with the mica schist. The latter, above the carbonaceous beds, contains a small sill of fine grained gneiss with biotite and muscovite.

To the north-east follows, usually with a SSW dip of 40--80°, a mixed series of mica schist, quartzite and sills of gneiss with two micas. The first gneiss contains tourmaline; the second—about 60 meters thick—is a real ortho-augengneiss. On its north-eastern side it is somewhat unconformable to the steeply erected mica schist. Samples of a peculiar metamorphic rock were gathered about one kilometer NE of Kapar Khan at + of pl. III section 6b. It is a repetition of micaceous tourmaline-bearing quartzite with garnetiferous mica schist and mica schist rich in tourmaline, the whole being about 20 meters thick.

From Binsar up to Jandi, the best view point of the snow mountains[1], the bedding planes are steeply inclined to S and SSW. The rocks are an intimate mixture of fine grained sericite gneiss with mica schist and chloritic phyllite, unfit for mapping the gneisses, which towards the bases become predominent. The thickness of this gneissic series of Jandi is estimated to about 3 kilometers.

Our section pl. III continues along the trail NE of Takula, where the gneiss dips 40—60° to the south. Although the outcrops are scarce, it obviously overlies a series with crumpled quartzite layers. Then follows a more regular stratigraphic series of a north-eastern dip, beginning with sericite schist which is supported by the limestone series of Batari-Dewaldhar. As seen from Jandi, it is the direct north-western continuation of the limestone which forms the range on the NE side of Jaingan Naddi at Kanari Chhina (p 30).

Above the limestone and dolomite with its thick bedding is a series of sericitic schists which seem to be supported by quartzite. This region of Bitaunsera, however, is not well exposed. Moreover it had to be traversed in a hurry, on account of a government order. The section plate III thus needs improvement. But towards the town of Bageshwar, the tectonic position is clear again: on the south side of the bridge over the mouth of the Gomati river is a cliff of quartzite dipping 65° to S, while on the opposite hill on the north side of the town the sericitic quartzite dips 35—40° to N 20E. Obviously the mighty quartzite series forms here an anticline and a syncline. But this syncline north of Bageshwar is not followed by the normal sediments. They are sericite chlorite schists of the Daling type passing into fine grained sericite gneiss. In its southern limb was found a layer of amphibolite. We therefore suppose it to be in an abnormal position, the syncline being filled with the remains of a higher thrust sheet. The width of this synclinal filling on the NW side of the Sarju river is half a mile. SE of it, on account of an axial pitch to the NW, it becomes narrower and seems to end in the air.

Farther up, the Sarju valley is for a long way cut out of a mighty quartzite series which dips more or less regularly 45—60° to SW. It is underlain by phyllite and limestone.

The vast region of Kapkot to Karbogat, Sama and up to Tejam, thence up the Jakala river, until Girgaon, is made of limestone and dolomite with more or less calcareous shales, folded and twisted with strikes in all directions.

At Kharbagar a normal anticline of W to WNW direction occurs.

Stratigraphically, a peculiar conglomerate is worth mentioning, which was found on the trail directly below the iron bridge of Kapkot. There, a thick bed of dolomite is overlain by calcareous strata with pebbles of quartzite up to the size of a fist, and normally covered again by limestone, the whole dipping 20—30° to S (Pl. III). It is apparently the same conglo-

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[1] See "Thron der Götter" 1937. Panorama Pl. Ia.

merate which was also encountered in huge blocks near the sulphur springs on the Ram Ganga above Tejam. The pebbles embedded in a schistose marble are of limestone, quartzite, reddish and somewhat sericitic sandstone and of less abundant gneiss. Quartzite pebbles were noted up to half a meter in diameter.

No real moraine was encountered in the Sarju valley. But some blocks in the river are of such a size that they can hardly have been brought down by the actual river. Thus, at Hatsila (sheet $53\frac{O}{NE}$) a block of quartzite was estimated at about 100 cubic meters. East of Kharbagar there is a gneiss pebble of about 2 cubic meters, although there is no gneiss in the neighbourhood.

The continuation of the Sarju section NE of Kharbagar is described by A. GANSSER, departing from the NE (p. 67, Pl. III, sect. 6c).

The Transverse Section of Jakala Valley and Gori Ganga

(Pl. II, Sect. 5 and Fig. 33)

a) Tectonics

The village of Tejam at the confluence of the Jakala River with the Ram Ganga is situated on three terraces, the lowest being eroded out of the black calcareous phyllite, about 15—20 meters above the river (1020 m. above sea-level). The next one is about 50 and the third one still 15 meters higher.

Tectonically, the section of the Jakala valley is a continuation of that of the Sarju river above Kapkot, but with a general dip of the calcareous sedimentaries to the north. It seems that the limestones form a great anticline pitching to WNW (Kharbagat).

If the series on the Jakala is normal, as it appears to be, the thickness is about 5,5 kilometers. It is a repetition of limestone or dolomite mainly in the state of marble, frequently sericitic and splitting into fine tables or stalks, interbedded with dark argillaceous slates or phyllites. The dip is 55—20°, towards north (not NE) as an average.

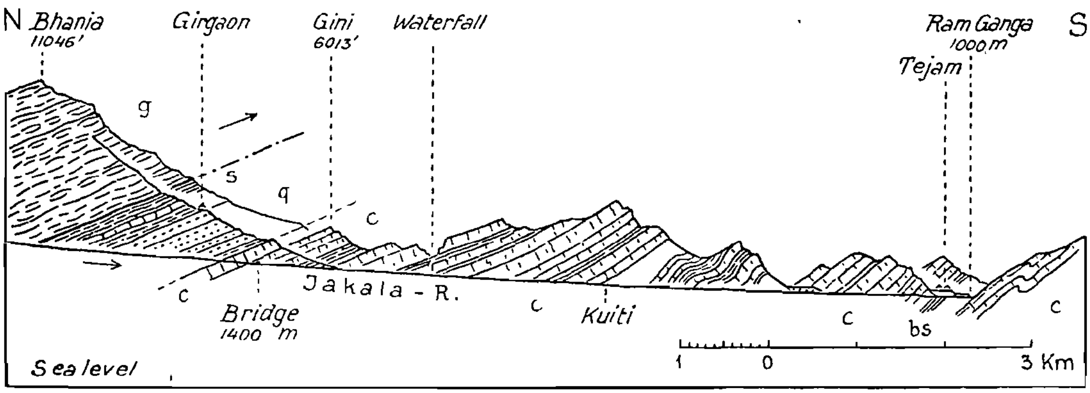


Fig. 33. The transverse section of Jakala River.
g = gneiss; s = sericite schists, partly with garnet; c = carbonate series (limestone, partly dolomitic and marble with interbedded slate; bs = black slate; q = quartzite.

At the bridge of Girgaon (1400 meters above sea-level), a massive wall of marble about 100 meters thick, dipping 20—25° to NNW, forms the top of the calcareous series. It is overlain by quartzite and phyllite. The trail from the dak bungalow of Girgaon to Mansiari follows

a zone of sericite- and chlorite-phyllite with layers of quartzite or quartz schists and occasional marble. An intensely blue scaly mineral was found in schisty quartzite, which under the microscope is determined by Professor Dr. C. BURRI as lazulite.

Curiously enough, this whole zone along the face of the high mountains strikes in an almost north-eastern direction, conforming to the deviated northwestern dip of the strata. But the striations of tectonical friction are not to NW, but to S30W according to the main tectonical movement.

This sedimentary series is thrust by augengneiss which forms the basis of a huge cristalline series cut across by the gorge of the Gori Ganga.

We now pass over to Mansiari and the Gori Ganga some 6 kilometers farther NE (Pl. II, sect. 5).

The exact contact of the gneiss-thrust was not found on account of smaller and larger landslips all along the thrust line.

Following the trail from the slope of Mansiari down to the Gori river and then upwards along it we first traverse again ortho-augengneiss of 50° dip to N, then come across repetitions of orthogneiss and paragneiss (psammite gneiss) dipping 30—40° to north. Muscovite gneiss alternates with muscovite-biotite gneiss, passing into a black schist composed almost entirely of biotite.

Above Rarar, the gneiss with its minor folds recalls that of Darjeeling.

At the overhanging camping rock of Baugdiar, (2500 meters) granular limesilicates occur. To the north of it, dykes of aplite and pegmatite traverse the northerly dipping biotite gneiss.

Above the bridge of Tibu the river has cut a narrow passage through walls of an unusually beautiful ortho-augengneiss with biotite and muscovite, the feldspar augen reaching a size of 10×20 centimeters. The upper conformable contact with the metamorphic sedimentary series is sharply modelled out and dips 38° to N15E.

Above the bridge of Nahar[1] (2750 meters) numerous dykes or veins and sills of aplite and pegmatite with muscovite and tourmaline traverse the oldest sediments in all directions, in places amounting to about 50% of the rock formation. (Phot. 24, Pl. XII). It is mineralogically the most varied division of the Gori valley and corresponds to that of the Kali below Budhi. Calcsilicate layers with diopside and chlorite schists also occur in minute repetitions with mica schist or paragneiss.

Finally, above the mouth of the Laspa creek, the igneous injection is dying out, and we enter a vast series of phyllite. The dip gradually decreases to 20° from Rilkot to Tola. The basis of this apparently Algonkian series at Rilkot shows the last effects of contact-metamorphism in the shape of garnet and biotite porphyroblasts in the phyllite. The latter are elongated in the direction S 30 W which is the direction of the main differential movement and not that of the dip of the strata which is towards NNW.

Reviewing the section of the Gori Ganga, we mention the huge series of gneiss and mica schist of about 16 kilometers thickness dipping towards the north and thrust over the calcareous sedimentary series of Mansiari-Rilkot. The crystalline series seems to be normally covered by a mighty sedimentary series of phyllite with an intensely injected basis.

b) Morphological Observations

From the desert climate of the plain, we have come to the region of abundant monsoon rain, where the main valleys are cut deep enough for an almost tropical climate with temperatures up to and above 40° C, and of tropical cultivation like that of bananas and rice. No wonder that under such conditions also red laterite-like earth was locally encountered (in Jakala Valley up to the village of Gudji at 1200 meters).

[1] These are uninhabited places in the gorge.

The Gori Ganga gorge above Mansiari is a typical case of unequalized slope (unausgeglichenes Gefälle) of the Himalayan transverse rivers. From Milam down to Rilkot the slope is gentle and the valley widened through the phyllite series with moraines and terraces. But from Rilkot down to near Mansiari, it is an unbalanced chain of gorges and rapids. The average fall on 20 kilometers in a straight line is 1700 meters. Considering the curves at Rarar and other smaller ones, the length would be 24 kilometers and the gradient even as much as 7 per cent. The main cataracts are below the mouth of Jamia Ghat, above Rarar and below the bridge of Tibu. At the latter place, over a length of about 400 meters, the gradient is as much as 18 degrees!

Moraines were found down to the Tibu bridge at 2700 meters. The glacier now ending at 3500 meters above Milam must have passed the narrow walls of the great augengneiss. There the vertical walls of the gorge are only about 40 meters apart. Thus, fine glacial striation was expected. But only slight smoothing was observed at the left issue, of uncertain glacial origin.

North of the mouth of the Laspa river, a great lateral moraine with blocks of granite and pegmatite of the former Poting glacier was found which reached the main valley. Farther down the Gori, typical moraine occurs just below the bridge one kilometer SE of Baugdiar, at 2450 meters. It may have come from the former Rarar glacier and from Parbat A, 5100 meters on the west side. Another moraine was noticed 2 kilometers further down the main valley, at about 2100 meters. As compared with the Kali river, no more moraine was to be expected at lower levels. But on the trail below Jamia Ghat, on a slipping slope at an altitude of 1550 meters, material of the appearance of ground moraine was encountered: round and angular pebbles of gneiss and biotite schist, embedded in sandy clay. Although no striated pebbles could be found, the question may be raised whether this occurrence is to be regarded as a relic of an older glacial period.

From Almora northward to Joshimath (Garhwal)

a) Tectonical Features

No geologist seems as yet to have followed the Kosi river north of Almora and entered Garhwal at Gwaldam in order to proceed over the Kuari pass to the tributaries of the Ganges. At least, as far as we know, nothing has been published and the map of the Himalaya, printed in 1934, leaves the region blank.

Our route, on the whole, was oblique to the strike, so that no general section can be presented. The main features are seen on our geological map 1 : 650 000. For detailed topography we refer to sheets 53, 1″ = 2 miles.

We first follow the new motor road from the bridge NW of Almora along the Kosi river. The flat mica schists of Almora, with their quartzite layers, are slightly synclinal at the western continuation of the Bari Chhina syncline. The northern limb again is steeply inclined and contains several intrusive bodies of augengneiss (Mekala, Gotakot, Parolia). West of Saumkotli, dipping 30° SW below the mica schist series, follows quartzite in vast extension. We are here in the western continuation of the overthrust of Kanari Chhina.

Along the flat valley bottom the outcrops are scanty as far as Someshwar, where the quartzite, with a normal strike, is vertical and then dips to the NNE.

Two miles north of Someshwar follows the zone of dolomite and limestone with interbedded sericite phyllite, faulted and gently dipping, then covered again by a big body of quartzite (some 1500 meters) dipping 30—40° NNE to N.

Obviously, the anticline or false anticline of Someshwar, with its dolomites and limestones, corresponds to the crumpled sedimentary zone of Badolisera-Kanari Chhina-Batari.

As expected, another thrust follows above it. It is well exposed on the road leading up in curves from the Kosi plain to the watershed of Kausani. An undulated smooth sliding plane on quartzite, with an average dip of 40° to NNW is overlain by 30—50 meters of chlorite schist. Then follows sericite gneiss and augengneiss. It contains amphibolitic norite or gabbrodiorite near the basis in form of several small sills of a total thickness of 5—10 meters.

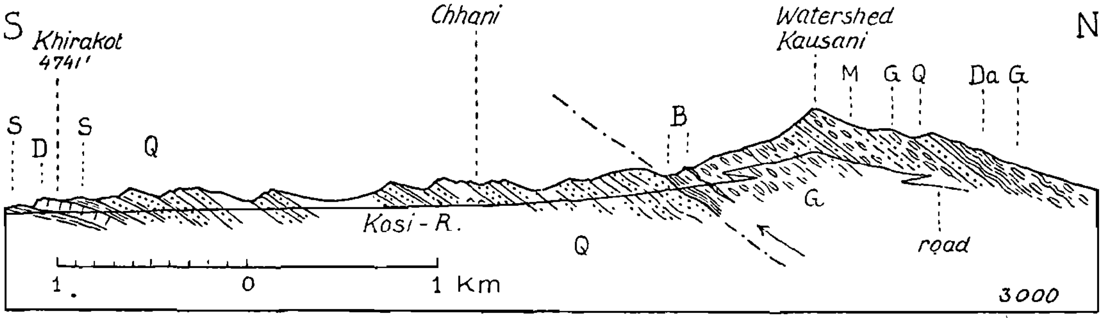


Fig. 34. The thrust of Kausani.
G = Sericite gneiss passing to fine augengneiss; M = Micaschist; B = Basic igneous; chlorite schists; Da = Sericite phyllite of Daling type; Q = Quartzite; D = Dolomite with phyllitic sericitic layers (S).

In descending to Garur, after having met with several more intercalations of augengneiss and quartzite, we traverse the fertile alluvial plain of Baijnath where excellent crops of wheat are gathered. The dip up to 45° towards the north or north-east remains unchanged on the low hills north of Baijnath.

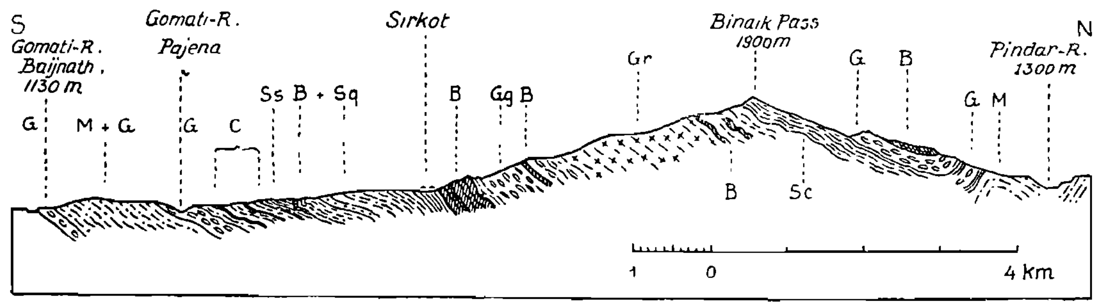


Fig. 35. The Section of Binaik Pass.
(Boundary of Almora- and Garhwal Districts, and Watershed to the Ganges.)
NW projection according to the average strike. M = Mica schists; Ss = Sericite schists; Sc = Sericite-chlorite-schists; Sq = Sericite quartzite; C = Carbonaceous series in schists; G = gneiss (augengneiss); Gg = Granite gneiss; Gr = Massive granite; B = Basic sills.

At Bajena, above mica schist, is exposed a granitegneiss. The latter is overlain by gently undulated mica schists with carbonaceous layers, similar to those of the Almora region.

Climbing over the ridge above Sirkot through pine woods, about 200 meters of chiefly basic green intrusives are crossed. They contain some sulphide ore and are interbedded with chlorite-sericite schist.

The main feature of the south side of the Binaik pass is a great mass of granite with slightly gneissic marginal zones.

The pass itself is on chlorite-sericite-schists, which support another series of augengneiss in the shape of a syncline of WNW direction (Fig. 35).

On the north side of the Pindari river the strike of the mica schists is perpendicular to their normal position, and the dip is 50 degrees to WNW. Up to the village Wan, at a distance of 20 kilometers, this abnormal position is predominant not only with regard to the mica schists: the quartzite too which underlies them after Bathleswar, and the calcareous series below the quartzite of the Wan valley strike to NNE. Because of such c o n t o r t i o n s, the structure of this and the following part of the wooded mountains of Garhwal is most intricate. Moreover, the trails are scarce and the topographic basis 1″ = 4 miles is the most primitive one of the Central Himalaya[1].

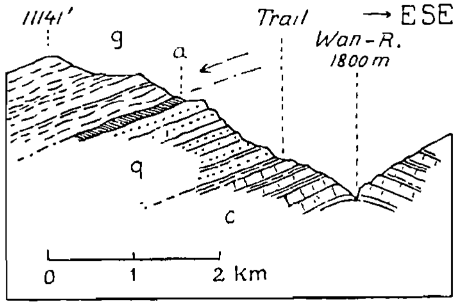
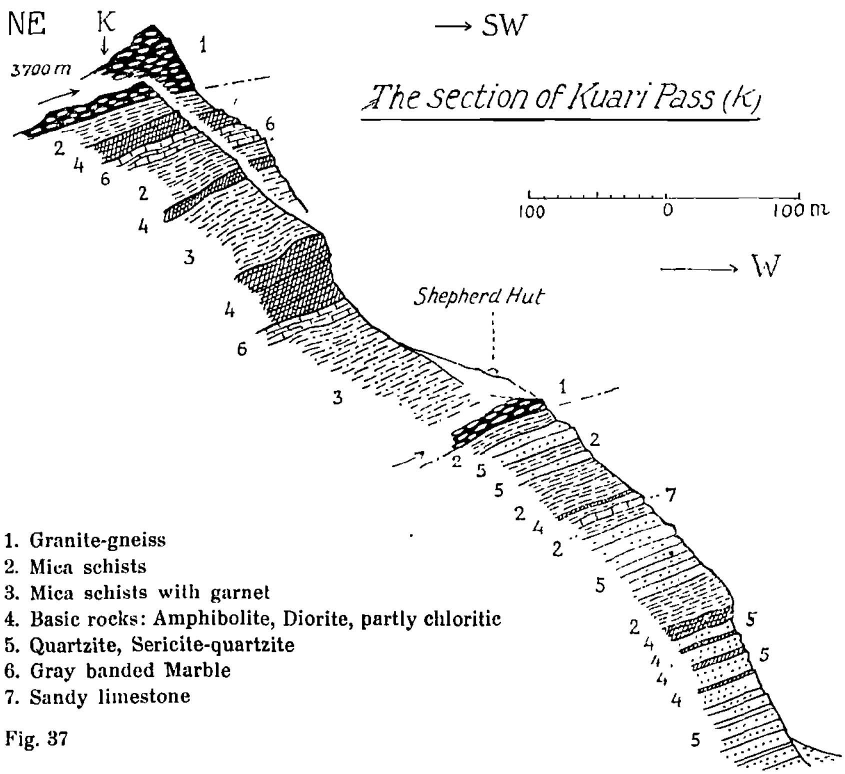


Fig. 36. Structural aspect of the Wan Valley.
g=gneiss and mica schists with biotite; q=quartzite; c = limestone series (marble) with black phyllite (type of Tejam); a = chloritic schists of amphibolite.

On the west side of the Wan valley, north of the Lohadjang pass, the quartzite series forms high walls. The dip is 20° to W 30—40° N. We could observe clearly that the limestone underlies this quartzite conformably. In conclusion, we must regard the mica schists with gneiss as thrust over the quartzite-limestone series (Fig. 36).

The pass of 3000 meters between Wan and Kanaul (Kanol) is eroded out of higher metamorphic schists, but in the Nandakini valley the limestone-dolomite series reappears in the shape of a window with a pitch to NW. Black and variegated clay slates occur too. The dips are in all directions. The steep slope north of the bridge is made of a thick dolomitic series, covered by phyllite, with dips of 45° to north. The latter again is overlain by the quartzite series.

The next pass above Ramri (Rawni) takes us over two quartzite series with intercalated sericite-phyllite, to the Birehi valley. A most complicated series of rocks follows on the SW side of the Kuari pass (3700-3800 meters), as shown in Fig. 37.



1. Granite-gneiss
2. Mica schists
3. Mica schists with garnet
4. Basic rocks: Amphibolite, Diorite, partly chloritic
5. Quartzite, Sericite-quartzite
6. Gray banded Marble
7. Sandy limestone

Fig. 37

[1] The new but still preliminary edition of 1936 sheet 53 N was not yet at hand for our geological research. It is a pity that the modern photogrammetric method is not yet applied in the Himalaya.

Possibly, this series is doubled or tripled. On the whole, the metamorphism again increases upwards.

The NE side of the Kuari pass is uniformly made of mica schists with quartzite and gneiss, dipping 20—40° to NE. It forms the basis of the great crystalline thrust zone from Joshimath to Badrinath.

b) Morphological Features

Except for the highest part of the Kuari pass, the whole country is wooded—in the lower regions with pine *(Pinus longifolia)*, in the higher regions with oaks, *Rhododendron*, firs *(Picea morinda)* and hemlock *(Abies Webbiana)*, and finally on the northern slopes with birch trees at an altitude of 3600—3800 meters. This jungle, together with the strong semi-tropical weathering made it difficult to understand the structure at a distance. In addition, the southern part of the lower Himalaya from Nainital and Almora to the Pindari, as seen from a high point, reveals the remains of a peneplain at an altitude of 2000—2500 meters (Phot. 5 Pl. VII).

The Pindari is a very active river. The floods of the monsoon season of 1936 caused numerous landslips on the borders, one of which buried a village and killed numerous people.

The Nandakini collecting its water from the Nandakna (6300 meters) and the Trisul (7100 meters), has cut an impracticable gorge through the quartzite and the limestone series, with typical convex walls.

The village of Ramri (2500 meters) on its north side is situated on the terrace of a vast landslide with blocks made of big carbonate crystals. Another subrecent mountain slide was encountered in the Birehi valley at Ghiugi. The wall from where it broke off in the NE is easily recognized. The scree material is about 200 meters thick and covers about one square kilometer[1].

Along the Pilgrimage Trail from Ranikhet northward to Karnaprayag

R. D. OLDHAM (51) seems to have been the first geologist who, already in October 1882 travelled along this trail. It is difficult to follow his non-illustrated description, because many of his names do not figure on the new maps. The eastern boundary of the gneiss was "seen to be fairly straight and presumably a fault".

MIDDLEMISS (42) mapped 1887 the crystalline Dudatoli mountains west of the trail, passing over Diwali Khal.

Forty-eight years later, J. B AUDEN (4, p. 133; 5a, plate 36), also of the Geological Survey of India, used the same way to go up to Badrinath. In his first paper he gives a short description of the rocks found along the pilgrim trail, without supplementing his account with any illustrative sections. He mentions also "the abrupt fault contact of the granite and schistose series of Dudatoli with the massive limestone to the east", as had earlier been described by MIDDLEMISS. In his later paper he shows this fault contact to be the line of a great thrust plane delimiting the schistose and granitic rocks of Dudatoli, belonging to his "Garhwal Nappe", from the underlying limestones. We also have come independently to the conclusion that this fault line marks the line of a great thrust coming from the north-east.

We begin at Ranikhet. This pretty and important place (1700—1900 meters) is situated on mica schists and white orthogneiss of gentle northern dip.

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[1] The Gona lake slide further down in the Birehi valley and the great mountain slides of the Dhauli valley will be dealt with in later chapters.

Descending northward to the Gagas river, a series of mica schists, quartzite and gneiss is traversed. The dip increases up to 40° to NE. A carbonaceous layer too was encountered about half way down (Graphitic phyllitic schist of AUDEN). The dip remains unchanged as far as the crest of Chaura, where the garnetiferous mica schists form a symmetrical syncline of WNW strike (Pl. I, Sect. 3).

At an angle of 45° the mica schists overlie an imposing mass of coarse granite. It contains muscovite and biotite, and forms the rugged hills south of Dwarahat. This important village with its schools, missions and numerous old Hindu temples is situated on a peneplain of 1500—1600 meters, formed of deeply weathered white gneiss, rich in muscovite, but with little biotite.

With 30—40° SW dip the gneiss is conformably underlain by sericite schists with garnet, below which follows slaty quartz porphyry. On the eastern side of the brook are some exposures of variegated shale recalling the Krol formation. The dip there is, on the contrary, towards NE. The walls up to the Dunagiri (fine view point, 7549') are made of limestone or dolomite and quartzite with a general dip more or less corresponding to the slope, i. e. towards SW (Pl. I).

Along the valley towards NW, quartz porphyry schists are exposed on the south-western side, dipping 30—50° SW. A fine place for studying these igneous rocks is Chaukhutia, situated on the border of the fertile alluvial plain (Fig. 38).

A highly interesting structure is found about a mile north of Melchauri, where the Ramganga has cut an epigenetic gorge through the folded limestone series (Fig. 39). At Melchauri this river deviates across the limestone series in order to traverse the contact region again, 11 kilometers farther SE, at Chaukhutia.

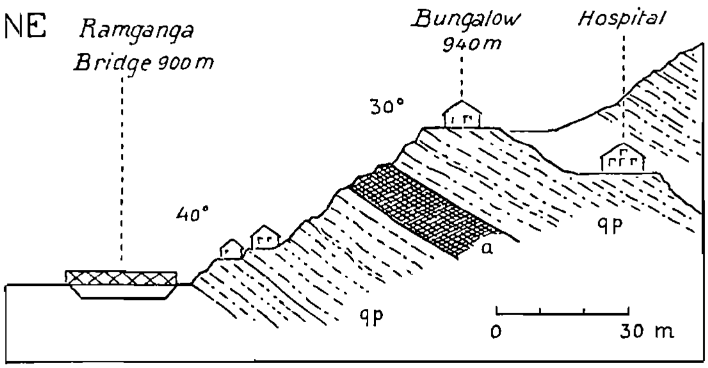

Fig. 38. The Igneous Rocks of Chaukhutia.
qp = Slaty quartz porphyry;
a = Amphibolite (altered basic igneous rock).

The limestone series interbedded with quartzite and green schists is intensely folded, the general strike being still to the NNW, conformous to the longitudinal valley, but with local

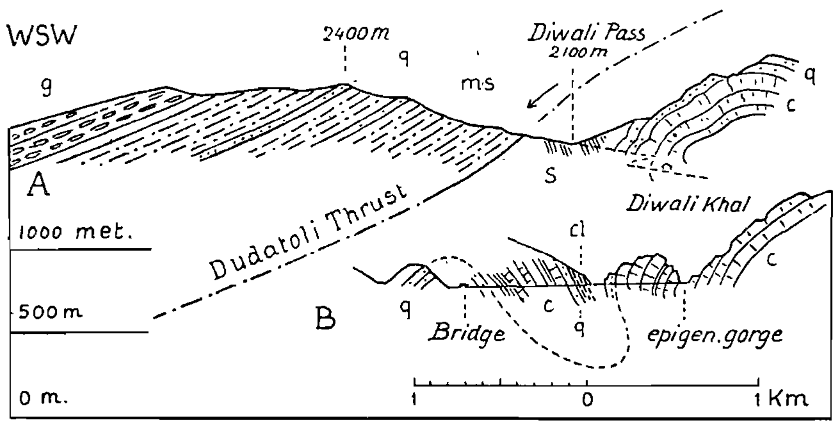

Fig. 39. Sketch of the Thrust Region of the Upper Ramganga.

A = Section of the Diwali pass; B = Section one mile north of Melchauri; ms = mica schists with garnet and quartzite layers; g = gneiss; c = limestone and dolomite; q = quartzite; s = slate; cl = green schist, chloritic (amphibolite).

deviations (Fig. 39 B). Proceeding farther to the NW and rising from Lohba to Diwali Khal, the crystalline series is seen overlapping the sedimentary folds. The trail cuts the thrust contact at Salana (top. sheet 53 $\frac{N}{SW}$, 1" to 2 miles). We are in the continuation towards NNW of the overthrust of Dwarahat.

MIDDLEMISS considered the abrupt contact to the unmapped limestone series to be a straight fault. However, this "fault" contact is far from being straight, nor is it vertical. Looking from Salana to Diwali Khal, it plainly appears as an overthrust shearing off the folded sedimentaries. Thus, the great synclinal region of gneiss and mica schists of the Dudatoli mountains is swimming. We may call it the Dudatoli thrust mass.

On the northern side of the watershed of the Diwali Khal pass, a tributary of the Ganges is followed for six miles. The trail, on the right side of the longitudinal valley, shows some exposures of quartzite and green schists belonging to the sedimentary series underlying the Dudatoli thrust.

Below Adbadri, the valley turns abruptly to the right and forms the transverse gorge of Ata Gad, showing the structure down to the Pindar river (Fig. 40).

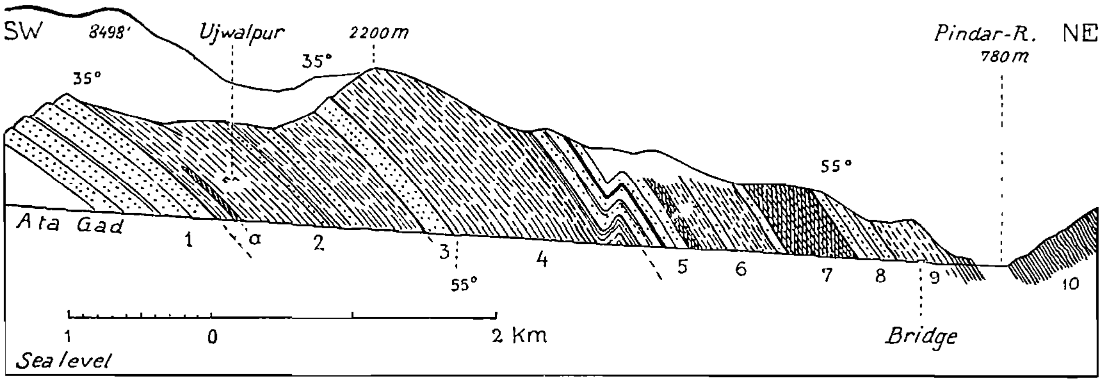

Fig. 40 The Transverse Section of Ata Gad between Adbadri and the Pindar River (in NNW projection).

1 = Main quartzite (Tal?); 2 = Greenish chloritic schists including quartzite and compact amphibolite (a); 3 = Quartzite dipping 35—55° E 40° N; 4 = Green schists dipping to ENE; 5 = Quartzite with amphibolite layers; 6—7 = Big series of amphibolite to chlorite-sericite schists; 8 = Quartzite with interbedded slates above the bridge, dipping 55° to E 25° N; 9 = Chlorite-sericite schists or slates, passing into: 10 = Dark phyllite, little metamorphic.

This series of 5—6 kilometers thickness seems to be in a normal position. It contrasts with all we have seen so far by the abundance of green schists and amphibolite of igneous origin.

Following the Pindari down to Karnaprayag, the bluish black and greenish slates of 50—60° dip to E 15 N are beautifully exposed at the bamboo hanging bridge of Simli. Another interesting outcrop is a thick body of tough amphibolite about 2 kilometers from Karnaprayag.

The Transverse Section of the Alaknanda from Karnaprayag to Joshimath

(Pl. IV, Sect. 7 and topogr. sheet 53 N)

a) Tectonics

The village of Karnaprayag is situated at the confluence of the mighty rivers Pindar and Alaknanda, both tributaries of the Ganges. A big body of nearly vertical quartzite striking regularly N 12° W forms the mountain on the SW side and is cut across below Karnaprayag in the shape of a gorge.

With a sharp concordant boundary follows to the northeast a series of about 1,5 km thickness of green chlorite-sericite schists passing into chloritic quartz schist with some minor

layers of amphibolite, and ending in a thick body (about 100 meters) of amphibolite. The dip, including a quartzite of 15 meters is 50—60° to E 20 N.

Then follows in continuation of the slate of the Pindar at Simli (Nr. 10 of Fig. 40) a zone of about 500 meters of black clay slate with little, if any, sericite. A small upright anticline of quartzite separates it from the next zone of slate (quarry of Jaikan). These and the next exposures cannot be figured properly in our N 30° E section, because the dip is towards E instead of NE.

After traversing a thick body of quartzite of 60° eastern dip, the rocky trail along the gorge passes over chloritic slate again. Then follows at Langasu a surprise: a nearly vertical wall of massive marble and amphibolite, both of a normal north-western strike. Two more marble beds (one of 50 meters) follow, separated by slates. The strike again turns, even to nearly west. The top marble thus strikes at a right angle to the basal quartzite.

The little village of Sunla (bungalow) and the more important place of Nandaprayag are situated on a mighty wavy series of sericite-chlorite schists with quartzite layers of the Daling type. The dip is normal to NE (Dalings upon Baxa?).

In this region the metamorphism increases upwards again. We come to stretched and sericitic quartzite and mica schists of north-eastern dip. Although the valley borders are terraced or made of landslips, the scanty outcrops seem to suggest a synclinal position 2 km north of Nandaprayag. Below a thick body of quartzite appears biotite-gneiss (about 500 meters thick, at Mathyana), and underneath it is the following series:

Amphibolite, about 200 meters (dip 40° to S 30 E), exposed at the iron bridge 2,5 km SW of Chamoli).

Quartzite with a layer of amphibolite, about 100 meters, crushed.

Amphibolite, 50 meters; sharp limit to

Quartzite of Chamoli.

This latter quartzite is characterized by massive beds, up to 2 meters each, of greenish colour, in a flat anticlinal position of abnormal south-eastern dip. On the section Pl. IV it cannot, therefore, be figured satisfactorily.

The quartzite of Chamoli is of great thickness and extension. At the mouth of the Birehi river and farther up this valley to the SE, the quartzite, being partly crushed and crumbling into sand, forms white hills. It is underlain by a narrow zone of gneiss and schistose amphibolite.

We now enter a vast region of carbonates: limestone, dolomite, chiefly microcrystalline, and marble interbedded with dark argillaceous shales and slates, together of over 1,5 km thickness. It is of the same appearance and tectonical position as the limestone series of Tejam and forms a great tectonical peninsula of about 150 square kilometers. All around its rugged contours the limestone series seems to be overlain by quartzite.

We have followed the limestone up the Birehi valley to Gona Lake. The fresh blocks of the great recent and subrecent mountain slides yield excellent specimens for petrographic study. Some blocks on the lake are nicely banded by a hundredfold repetition of microcrystalline limestone and dolomite, each layer measuring a few millimeters to several centimeters. Possibly they represent yearly deposits. The dolomite layers frequently show a yellow to orange surface weathering. The gray layers are siliceous and resist leaching more than the marble sheets.

Two analyses of a banded rock, I of a white band, II of a gray band, show the following composition

		I	II
in HCl unsoluble, mainly	SiO_2	7,69 %	59,11 %
	Fe_2O_3	1,11 %	4,42 %
	CaO	50,20 %	11,23 %
	MgO	0,42 %	6,04 %
	CO_2	40,43 %	17,34 %
	H_2O	0,15 %	1,36 %
		100,00 %	100,00 %

While some blocks show little, if any, structural deformation, a great part of the series is intensely stretched and minutely folded. Besides argillaceous intercalations, there are also some of green chlorite schists. They are seen with the field-glasses at the precipice above Gona, and thence extend north-westwards to Pipalkoti. The average dip above Gona is 30° to E 15 N, flattening towards east (Fig. 41).

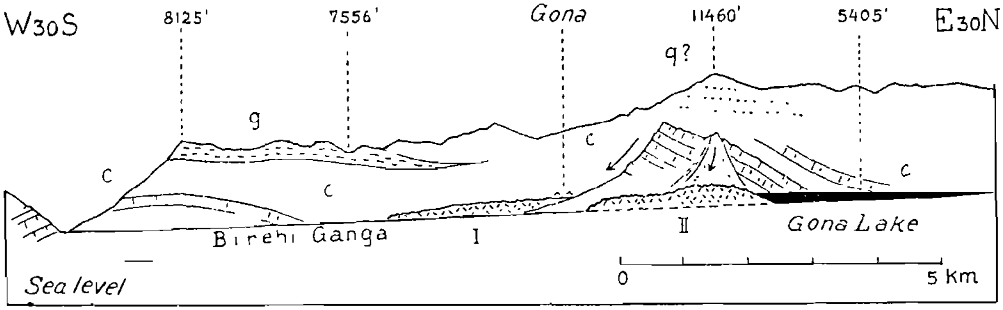

Fig. 41. Situation of Gona Lake. Projection to N 30 W.
g = Gneiss; q = Quartzite; c = Limestone and dolomite series; I = prehistoric, II = recent mountain slip.

The tectonical position in detail is not yet deciphered. The top region of the high mountain, 11460' of the map $53\frac{N}{SW}$, above Gona Lake is apparently made of quartzite, as an eastern prolongation of the quartzite of Chamoli. It seems to cut off the limestone series. Even more peculiar is a band of gneiss forming the western crests 8125' and 7557'. It is encountered on the trail over the gap 7556' on the wild crest above the limestone, and seems to be covered again by limestone. Possibly it is something similar to the gneiss bands in the mesozoic limestones or slates of the Penninic thrust region in the Alps.

Returning to the Alaknanda, the structure is simpler and plainly seen on the north-western side of the deep gorge at Pipalkoti. The strike is normal: W to WNW. The series of limestone and dolomite passes into, and is interbedded with, dark to carbonaceous clay-slate. It is very little metamorphic, but regionally traversed by a distinct cleavage of 45 to 65° northern or north-eastern dip. Caps of quartzite are recognized at a distance (Pl. IV). The best exposures for close study are at the Patal bridge, above point 3744' of map 53 N, where a landslip had recently damaged the trail (Fig. 42).

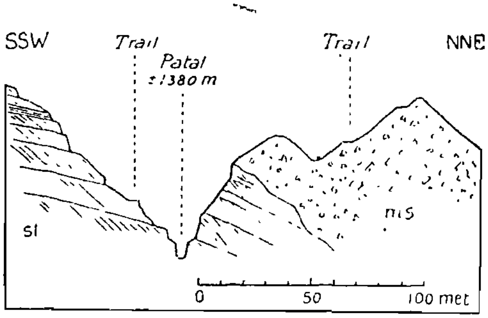

Fig. 42. The Epigenetic Gorge of the Patal below the Bridge.
sl = Dark slate with cleavage
ms = Old mountainslide material.

Opposite Hilang, below the mouth of the Urgam valley, we come to the interesting boundary of the limestone series, where already Auden noticed a series of mica schists and biotite-gneiss apparently overlying the limestones and presumably thrust upon them.

According to our rapid observations and designs, the succession from below is about as follows, at 40° dip to NE:

a) massive crystalline limestone
b) about 500 meters of Chamoli-quartzite
c) about 150 meters of massive coarse marble (crystals in certain places up to 5 cm, recalling Ramri)
d) quartzite and sericite-chlorite schists of the Daling type at the mouth of the Urgam valley (opposite the bridge of Hilang)
e) mica schists interbedded with quartzite
f) biotite-gneiss with fluidal internal folding, of the Darjeeling type.

Plainly enough, the crystalline silicates are thrust over the limestone-quartzite series. But the question is whether there is a reversed zone between. The main thrust plane is apparently to be considered either between c and d or d and e. Possibly the reduced Dalings are the remaining part of a reversed limb.

Proceeding farther upwards to Joshimath and Vishnuprayag, the rocks are predominatly of gneiss with a similar north-eastern to northern dip. The interbedded quartzites seem to have preserved part of their original position, pintching out locally or showing slight unconformity to the gneiss or mica schists.

b) Morphological Features

Along the old trail, on which every year 50—100.000 pilgrims travel, the Alaknanda valley has been deforested and the landscape is devoid of beauty. It is, however, of some interest in connection with terraces and mountain slides.

A terrace of about 30 meters above the river is indicated on the slates in the gorge 2—3 km NE of Karnaprayag. Older terraces of 60—80 meters are well preserved above Langasu. Nandaprayag is situated on a pretty terrace of about 50 meters, in the corner of the Nandakini and Alaknanda rivers.

2½ km N of Nandaprayag, the whole eastern mountain slope of mica schists has slipped down, apparently gradually and at intervals.

The position of Chamoli is characterized by a long intersected terrace of about 50 meters. All these terraces seem to be parallel to the actual course of the river.

At the river bend NE of Chamoli we saw in the distance a huge field of old mountain slide material, in the shape of rounded heaps of quartzite and limestone blocks. There seem to be two niches of breakage (Abrissnischen). The slide deposits may cover about 10 square kilometers.

A famous historical case is the Gona slide of the Birehi valley[1]. The rock fall occurred in September 1893. But the catastrophe only came to pass nearly a year later, on August 26th 1894, when the water broke through the dam, and damaged the valley far down. The heaps of scree material made of limestone and dolomite cover about 1,5 square kilometers and had a maximum thickness of 300 meters (Fig. 41). We estimated the volume at about 150 000 000 cubic meters. The lake was 4 km long and had a maximum width of 0,7 kilometers. The length is now reduced to 3,2 km, the depth having diminished from 150 to 120 meters. The surface of the water is at 5405′ = 1650 meters. We estimated the height of the rock fall to be about 1000 to 1200 meters. The type of Gona, amongst the 20 types of mountainslides distinguished by Albert Heim, is his No. 15, called Fallsturz (Felssturz) which means rock fall. The limestone mass has broken off not from a slippery argillaceous bed, but from a dry rock wall across the stratification.

Another similar mountain slide, probably pre-historic, was found immediately to the West. It has broken off from the higher neighbouring peak, and apparently once covered an even larger surface (I of Fig. 41). It must have dammed not only the Birehi valley, but also filled the mouth of the opposite side valley south of Gona. The length is about 3 km and the height 1500 meters.

At Pipalkoti and north of it, the Alaknanda has cut an imposing gorge into the limestone series. Both sides of the river show the typical convex shape, steepening downward. The village is situated on fertile oblique terraces near the edge of the escarpment.

An extended sliding field is crossed by the pilgrimage trail 4 km NE of Pipalkoti. The tired traveller is not likely to forget it, as he has to do a bit of hard climbing to cross the dangerous region.

[1] R. R. Pulford: Narrative Report on the Gona Lake and Flood etc. Lucknow. Nov. 14. 1894.
Albert Heim: Bergsturz und Menschenleben. Zürich 1932, p. 173.
Arnold Heim und August Gansser: Thron der Götter 1937, p. 223, Textf. 13 and phot. 216.

The last mountain slide before reaching Joshimath, still within the limestone window, has filled the side valley SE above point 3744′ of Patalganga bridge. Judging from the erosion which has occurred since, it may be pre-historic. The scree material forms a crest above the original valley, the creek having deviated and cut an epigenetic issue (Fig. 42).

The material of this old Patal slide derives from the background of the Patal valley and has reached the right bank of the Alaknanda. Obviously, the contents of clay and the cleavage have greatly facilitated the breaking off and slipping of such mountain slides caused by the deepening of the erosive basis.

Petrologic Studies

by A. GANSSER

1. The Basic Sills of the Border Region

a) Naini Tal

The occurrences of basic rocks east of China Peak were already mapped by MIDDLEMISS in 1890 (44). The sills are perfectly conformable to the shales which we supposed as belonging to the Lower Krol series. The best exposure was found at the saddle NW of point 7864, where the sill dips 30° to W 15 S and is several meters thick. It is more or less chloritized.

The microscopic examination of a fairly fresh specimen allowed to determine the rock as a diorite.

The plagioclase forms rather large lath-shaped elongated individuals and is an andesine-labrador. The next important mineral is an augite of light brown colour. The average extinction n γ c is about 45°. The angle of the optical axis is relatively small. Magnetite is fairly abundant, and also idiomorphic apatite and chlorite, the latter formed out of augite. Quartz is of subordinate importance and occurs in the shape of irregular grains, partly formed by myrmekitic unmixture. Quartz, leucoxene and pyrite are the accessory minerals. The texture is ophitic.

The basic sills are somewhat arranged in layers, usually traversed by cleavage, and tectonically deformed. The grain becomes finer towards the edge where the rock is also more altered, as seen by its more greenish colouring. The plagioclase is macroscopically no longer clearly recognizable. Under the microscope, however, the same mineral composition is recognized. The plagioclase is somewhat sericitized. Locally, calcite is also secreted. The chlorite derived from augite is more abundant. Quartz too is more plentiful and even discerned with the naked eye, forming certain streaks. The myrmekitic reaction with plagioclase is nicely defined.

No contact metamorphism is recognizable, probably too on account of later tectonical transformation.

b) Bhowali

The basic igneous rocks exposed along the road above Bhowali form large massive greenish rocks of a reddish weathering colour. They show characteristic oval amygdaloid vesicles up to 1—2 centimeters in size, filled with intensely green epidote. Macroscopically no other minerals are recognized in the fine-grained rocks. Even under the microscope the different minerals are small and partly decomposed by epidotization and uralitization.

The basic zones of Bhowali are of the same type too, and mainly regarded as an epidotic diabase. The chief components are small lath-shaped stalks of andesine-labrador. They are frequently epidotized. Small brownish augites are intercalated between the ophitic plagioclase. They are partly uralitized and chloritized. The uralite is easily recognizable by its intensely green pleochroism. The chlorite usually forms rather large patches which,

however, are not transformed from augite, but are in connection with the amygdaloid epidote. This latter mineral is abundant in the following shapes: a) as small pale to colourless grains, the result of secondary alteration, and b) as rather large, intensely green (ferruginous) individuals filling the vesicles; c) the rather large patches are often made of granular epidote with a rim of colourless epidote needles. The latter mingle with chlorite individuals as the last formed amygdaloid components.

Finely spread leucoxenized titanite is found as an accessory mineral. The lack of ore is remarkable in contrast to the basic sill of Naini Tal. The interesting vesicles of epidote, sometimes mixed with rather large plagioclase, may originate from primary gas bubbles, filled with carbonate which was transformed to epidote.

2. The Gneissic Quartz Porphyry of Ramgarh

The mighty crystalline rocks of the region of Ramgarh, NE of Naini Tal, are determined as metamorphic quartz porphyry, some ordinary gneissic or schistose intercalations excepted. Macroscopically the dark gray rock with biotite shows white spots of feldspar and dark glassy quartz grains. The gneissified rocks are of an irregular schistose structure and may be designated as quartz porphyry-gneiss. The microscope discloses the following mineral components:

The phenocrists are perthitic orthoclase and rounded quartz.

The quartz grains are well defined, without showing cataclastic borders. Orthoclase is more abundant than quartz. The larger crystals frequently show cracks filled with quartz. Less plentiful and smaller is the microcline with its characteristic quadrille structure. The albite is usually confined to the fine-grained matrix.

The groundmass is chiefly formed of fine quartz grains, tiny scales of biotite and sericite, and subordinate plagioclase. The biotite is striking on account of its olive-brown to green pleochroism. It is usually concentrated in layers. Also nests of biotite are formed around a titanitic magnetite. The latter frequently has a border of titanite. Apatite is usually limited to biotitic layers. Chlorite is rarely found with biotite. Calcite is a secondary mineral and chiefly connected with the larger feldspars. The dark colour of the groundmass is caused by the abundance of tiny biotite scales. The sharp distinction of groundmass and phenocrysts characterizes the porphyritic texture.

3. The Crystalline Zone of Ranikhet

Towards Ranikhet we find a similar increase of metamorphism as at Darjeeling.

The sericite schists, along the motor road, are gradually transformed into garnetiferous muscovite-biotite schist. The rounded garnets with their centripetally concentrated inclusions, such as quartz and magnetite are striking. Peculiar is also the marginal limonitisation of the garnets following the cracks. The rock is of an extreme crystallisation-schistosity. The aluminium silicates, such as staurolite and kyanite, like those of the garnet-mica schist-zone of Darjeeling, were however not encountered at Ranikhet.

Gradually the mica-garnet schists are injected by aplitic gneiss layers. The former are transformed into tourmaline- bearing muscovite-biotite gneiss. The garnet is usually scanty. Together with the ordinary minerals of the mica schists is found clear albite with well defined twin lamellas. Brown pleochroitic biotite is more abundant than muscovite. The micas account for the lenticular schistosity. The above mentioned injected schists form the basis of the orthogneiss of Ranikhet.

The normal and widely distributed type of ortho-gneiss is a very acid white muscovite-alkalifeldspar gneiss (granite gneiss) of fairly uniform medium-sized grain and with somewhat lenticular feldspars. Biotite is not present, muscovite abundant and of a fairly large

size. The latter is slightly greenish. Even under the microscope a slightly greenish pleochroism is recognized. This would point to phengitic muscovite. The optical axis, measured on isolated scales, points however to normal muscovite. ($2V = 34°$).

As accessory minerals of the Gneiss we must mention rounded xenomorphous apatite. Here and there idiomorphic needles of tourmaline are also present. They are usually confined to aplitic layers within the gneiss.

Another type of gneiss, somewhat less acid, is also found, with rather large augen, more scaly, with biotite in addition to the muscovite and with cataclastic quartz. The augen are mainly formed of orthoclase. (For the chemical composition of the Ranikhet gneiss see the following chapter.)

4. The Crystalline Zone of Almora

Also in the Almora region a progressive metamorphism was found upwards of the sericite schists and quartzites.

The tabular quartzites are usually interbedded with sericite schists which may contain garnet.

The microscopic aspect of a fine-grained sericite-quartzite is as follows:

The predominant quartz is formed of evenly sized parallelepipedic grains of slightly undulous extinction. The fine scales of sericite or muscovite form layers of strictly parallel orientation. Tourmaline was noted as an accessory mineral. Dark layers within the white quartz are recognized macroscopically and under the microscope as rutile, granular titanite and tourmaline. Probably pneumatolitic iufluences account for such local mineral enrichment.

Another type of rock interbedded with the lighter coloured quartzite layers is a grayish brown schist of fine silky lustre. Under the microscope it is determined as biotite-muscovite schist, rich in uniformly orientated scales of the micas. Quartz is present in tiny grains. Also tiny grains of magnetite are distributed through the rock. The striking amount of biotite does not point to pure "epi-conditions", but to the proximity of the injections.

The garnets, as well as the rather large micas, and accessory hornblende point to a higher stage of metamorphism.

The average type of the characteristic garnet-mica schist of Almora contains the following minerals:

The originally well defined muscovite scales are mainly sericitized, so that the single scales are obliterated. Quartz is irregularly concentrated, usually in the shape of rather large grains of undulous extinction. Of special interest is the idiomorphic garnet, characterized by small drop-like central inclusions of quartz and magnetite. The surface is slightly limonitized. Large idiomorphic needles of hornblende have been observed in one of the slides. The extinction Z/c is $20°$ on au average. The intense pleochroism is X, Y = olive green, Z = dark blue-green. Large and intensely pleochroitic chlorite scales seem to derive from biotite, which is found in relics. The accessories are tourmaline (bluish gray, pleochroitic), magnetite and ilmenite, little epidote and limonite.

The texture is lepidoblastic-porphyroblastic (garnet), the structure schisty.

In coutrast to the gneissified ortho-rocks of Ranikhet, we found south of Almora town a large complex of massive muscovite-biotite-granite (Section 6a Pl. III). The wooded "Granite Hill" shows clear outcrops including its northern contact. The large idiomorphic feldspar (2 centimeters) gives the rock a porphyritic appearance.

Inside the granite mass there are often more basic inclusions with biotite of a pre-granitic schisty relic structure.

The composition of the granite is as follows: Large perthitic orthoclase and quartz of a slightly undulous extinction are the main components. Plagioclase of the oligoclase-

andesine type is less abundant. Twin lamellas are usually indistinct. Occasionally the plagioclase shows zonar growth with a somewhat more acid core. Muscovite and biotite are well defined. The biotite, of a pleochroism from brown to reddish brown, frequently contains inclusions of zircon. Their pleochroitic haloes may have some bearing on the age of the granite. The relatively large diameter of the haloes points to a higher age than Tertiary as some Himalayan Granites are considered to be.

The biotitic inclusions in the Granite are determined under the microscope as relics of biotite-psammite gneiss, the muscovite of which only occurs in fine subordinate scales.

On the north side of Granite-Hill, the contact is exposed to the mica schist-quartzite series of Almora (Fig. 43).

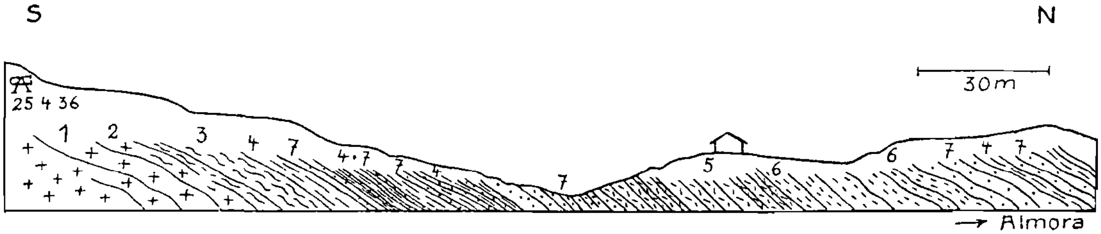

Fig. 43. The Granite Contact South of Almora.
1 = Coarse granite; 2 = granitic gneiss; 3 = lenticular gneiss to quartzitic gneiss; 4 = mica schists; 5 = mica schists with garnet; 6 = mica schists with fine quartz layers; 7 = quartzite, mainly sericite quartzite.

Towards the contact the massive granite is getting tabular (plattig). The schistosity increases and the granite passes into a biotite (muscovite) gneiss (2). The large orthoclase crystals are broken up. Large uniform individuals are lacking. The content of plagioclase somewhat increases (slightly basic marginal facies). The biotite, contrary to the granite, shows no pleochroitic haloes. The muscovite is mainly transformed into sericite. Sporadically a xenomorphic garnet occurs. The schistosity of the granitic gneiss, still containing biotite and muscovite, increases. In place of kataclastic structure recrystallisation is recognizable. The orthoclase forms large "augen" surrounded by mica. The single scales of mica are, however, not twisted. Apatite is frequent. Further accessory minerals are epidote, titanite and zircon. The latter is again included in the biotite and shows pleochroitic haloes.

Muscovite-quartzite gneiss to muscovite-quartzite are formed by an increasing amount of quartz. They overlie the gneisses described above. Macroscopically they still resemble a normal gneiss, but they are by no means equal to the normal quartzites of the Almora zone. The quartz grains are interlocked in a lobate shape and show no or very slightly undulouse extinction. Biotite is lacking, and the muscovite irregularly distributed. Together with the latter is found another colourless mineral of the appearance of muscovite, but of much lesser birefrigence. The refrigence is like that of muscovite. The mineral is biaxial + with an angle of the optic axis $2\,V = 24°$, as against 45° of the muscovite in the same rock. It must be a colourless chlorite, perhaps amesite according to its optical character.

The mica schists are formed by a diminution of the feldspars and increase of the schistosity. They in no way differ from the Almora types already described. It is an interesting fact that the higher metamorphic garnetiferous schists are found not directly at the granite contact, but only outside a zone of quartzite and ordinary mica schists.

No undisputable primary contact-metamorphism was observed. The formation of gneiss is due partly to a primary marginal facies of the granite, partly to tectonical effects. However, the metamorphism seems to be in some connection with the granite intrusion, although not confined to the direct contact.

5. Result of an Analysis and Summary

An analysis of the normal muscovite gneiss from Ranikhet had the following result (analyst Prof. J. JAKOB):

Analysis 4	
SiO_2	73.51
Al_2O_3	14.58
Fe_2O_3	0.56
FeO	0.72
MgO	0.12
CaO	0.62
Na_2O	3.85
K_2O	4.97
TiO_2	0.20
P_2O_5	0.22
H_2O+	0.80
H_2O-	—
	100.15

NIGGLI-values	Muscovite-Gneiss	Type of Magma
si	424	450
al	49.5	46
fm	7.0	6
c	3.5	3
alk	40.0	45
k	0.46	variable
mg	0.15	0.15

Being certainly an ortho-gneiss, the type of magma was determined after the table of NIGGLI[1]. It is thus alkali-granite-aplite, as shown by comparison in the last column.

As at Darjeeling, so in the region of Ranikhet-Almora, a certain increase of the metamorphism upwards could be determined. However, the boundaries in the Central Himalaya are much better defined. Usually the single bodies of orthogneiss are sharply separated from the mica schist series, and the somewhat migmatitic character of the Darjeeling gneiss is missing. The difference is also indicated by the analysis.

6. The Outliers South of the Central Gneiss Thrust

a) The Northern Part of the Almora-Ranikhet Zone

Of this complex zone traversed in four different regions, only the main types or those of special petrologic interest will be mentioned, proceeding northward.

The occurrence of carbonaceous beds in the mica schist series was partly already known to former observers. Microscopically these schistose rocks of black colour prove to be of a very simple composition. The main components are elongated psammitic quartz grains of little undulatory extinction, and a finely distributed, granular graphitoid substance. This pigment is occasionally concentrated in patches. The hardly micaceous rock may be called a graphitoid quartzite.

Orthogneiss and partly also basic sills have more and more intruded into the zones north of the synclinal graphitoid series. The best exposures are from Bari Chhina to the pass of Dhaul Chhina (Fig. 21). The average type is a muscovite-biotite alkalifeldspar gneiss (augengneiss). The large perthitic orthoclase arrests attention. Marginally, it is frequently myrmekitic. The acid plagioclase only shows twin lamellas near the orthoclase. Together with biotite and muscovite, it is also found as an inclusion in the lenticular orthoclase. The larger plagioclase shows a slight zonary growth. Muscovite predominates over biotite The latter generally only occurs in the shape of tiny dark-brown scales. The texture of the rock is granoblastic-porphyroblastic.

Other gneiss intrusions are characterized by large white augen up to 8 centimeters in length. This muscovite-biotite-augengneiss contains more biotite and in larger indi-

[1] P. NIGGLI, Die Magmentypen. Schweiz. Min. Petr. Mitt. Bd. XVI, 1936.

viduals. The borders of the large alkalifeldspars are nicely myrmekitized. The occurrence of garnet was not expected in this rock.

Similar trains of orthogneiss are also found on the trail to Binsar. The mineral composition of a tourmaline-bearing alkalifeldspar gneiss at Dinapani is as follows:

Reticular microcline is frequent. The acid plagioclase is an albite-oligoclase with clear cleavages and twin lamellas. The quartz is irregularly lobate, little undulatory, but with distinct "Felderteilung". The distinct schistosity is chiefly due to the muscovite. Biotite seems to be lacking. In its place there is much tourmaline which is less frequent in the rocks rich in biotite. Apatite and garnet are found as frequent accessories.

Associated with this gneiss are rocks with little or no feldspars which, however, resemble the gneisses by their same content of muscovite and tourmaline. Apatite is the main accessory mineral. Perhaps these tourmaline-muscovite schists are a marginal facies of the orthogneiss.

Although only at a short distance from Binsar, the paragneisses and schists of Bari Chhina are richer in biotite and poorer in tourmaline. The average type may be called garnetiferous biotite-muscovite-psammite gneiss. Quartz predominates over albite. The latter usually does not show twin lamellas. The biotite is of a greenish pleochroism X = pale yellow; Z = olive green. The idiomorphic garnet frequently shows quartz inclusions. The main accessories are chlorite, apatite and magnetite. Epidote and zircon are less frequent.

Descending from the Dhauli Chhina Pass to Kanari Chhina, a greenish fine-grained type of gneiss was encountered, sprinkled with white feldspars. This porphyritic epidote-biotite-muscovite augengneiss is more basic than those of Dhauli Chhina and Binsar, and tectonically more influenced. The augen are mainly formed of sericitized alkali-feldspars (orthoclase). The green colour is derived from the scaly olive-green biotite to which are associated epidote, quartz and plagioclase in the granular groundmass. Similar, more basic epidotized gneisses were also encountered between Binsar and Takula in the same lower part of the great thrust sheet.

On the Kosi River south of Someshwar and north of Ranikhet, orthogneiss trains were found of the same types as those described, in accordance with their tectonical position which is considered as belonging to the same thrust mass. We cannot enter into the many local varieties.

At Chaukhutia, north of the large augengneisses of Dwarahat, and apparently below them, good exposures of metamorphic quartzporphyry were found (Fig. 38). The sprinkling of feldspar and quartz of the gray schistose rock is recognized even macroscopically. Under the microscope the quartz forms large rounded grains of intense undulatory extinction. The orthoclase is perthitic, more or less idiomorphic and in parts reticularly albitized and calcitized. The plagioclase (oligoclase-andesine), if present, shows calcite secretion. The fine ground mass is chiefly quartz, sericite and brown biotite.

The texture is porphyroblastic, the structure lenticular. The mineral composition too is that of a quartz-porphyry, similar to the quartz-porphyry gneiss of Ramgarh. In both cases they are probably old intrusions, like those of gneiss. At Chaukhutia it may be a porphyritic marginal facies of the gneiss.

Some words must be added regarding the basic sills within the crystalline rocks found at Dhauli Chhina. The thickest of them, of about 30 meters, is intercalated between greenish augengneiss south of Kanari Chhina. The sill is not uniform and composed of more or less granular or darker zones. The brighter parts are a rather coarse diabasic amphibolite. The massive rock shows under the microscope an optic texture of a basic lath-shaped andesine with interbedded large hornblende individuals. The plagioclase forms clear twin lamellas,

though being partly altered to epidote and klinozoisite. The large hornblende is but very little pleochroitic: X = pale yellowish; Y = pale olive-green; Z = pale blue-green. The extinction is Z c = 24°. The basal planes of the hornblende are finely fringed. Although forming large crystals, the hornblende probably derived from augite. Relictic augite was not observed. Ore is found in the shape of titaniferous magnetite with wreaths of leucoxene and titanite. The whole composition of the rocks points to a metamorphic doleritic diabase.

The darker streaks of the same basic sill are finer-grained and characterized by an enrichment of hornblende in place of plagioclase. This diabasic amphibolite corresponds to the lighter-coloured streaks. The fine-grained hornblende is xenomorphic and usually somewhat zonar, the core being more definitely pleochroitic olive-green.

The contacts are not clearly exposed. It seems that they are sharp, without showing contact metamorphism. Usually these contacts are rather young sliding planes of local development, the massive intrusive bodies slipping on the mica schists.

b) The Crystalline Zone of Askot

The gneisses and crystalline schists of Askot overlie the sericite quartzite of Berinag. The latter is already so highly metamorphosed that an exact boundary of the thrust cannot be traced. The dioritic sills usually found between gneiss and quartzite are missing.

The sericite quartzite of Berinag is strongly micaceous at the border towards the gneiss and hardly distinguishable, macroscopically, from a superacid sericite gneiss. It is chiefly formed of kataclastic quartz. The size varies from large augen-like phenocrysts to fine psammitic grains of the ground mass. Somewhat xenomorphic apatite and epidote are rare accessories. Compared with other quartzites, the undulatory extinction of the quartz is striking. It must be in connection with the proximity to the thrust.

Large masses of uniform gneiss are found east of Tal. At about 3 km occurs an acid tourmaline-bearing muscovite-alkalifeldspar-gneiss, abounding in lobate intergrown quartz. The perthitic orthoclase is in parts reticularly albitized. The oligoclase-andesine partly shows the twin lamellas. The muscovite scales are irregularly distributed. Tourmaline, locally concentrated in the shape of idiomorphic needles, is recognized already with the naked eye.

The average gneiss forming the Dechula (Point 7651') is a biotite-muscovite-alkalifeldspar gneiss. The mineral composition is the same as that one of the gneiss described above, the occurrence of a chestnut-brown biotite excepted.

Besides these acid ortho-granite gneisses, the northern contact zone is of special interest. It is a tectonical contact. The basic sills, which we missed at Berinag, are present at Askot. Biotitic garnet-mica schists occur, similar to those of Almora. The large garnets have frequently been twisted somewhat after their formation, the holes formed thereby are filled with quartz. Towards the contact with the quartzite, at the Sirakot Temple, the garnet-mica schists are interbedded with chloritoid-phyllites. Their chloritoid which is of special interest, is recognizable even macroscopically as small greenish black scales. Under the microscope it is distinctly pleochroitic: X = pale green; Y = sky-blue; Z = yellowish green. The positive angle of the axis is 2 V = 40° on the average. The scales are partly sieve-like pierced by quartz. On the other hand the relictic shape points to resorption. Other inclusions, usually known from chloritoid, are lacking. In their place the polysynthetic twin lamellas occur, as already described from the Swiss Alps.[1]

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[1] A. GANSSER: Der Nordrand der Tambodecke. Geol. u. petrogr. Untersuchungen zwischen San Bernardino und Splügenpass. Schweiz. Min. Petr. Mitt. Bd. XVII, 1937.

The basic sills at the boundary of the quartzite and the crystalline rocks are well exposed at Sirakot. They may also be found within the quartzite, and are usually of uniform composition even over long distances. Macroscopically, these fresh rocks are speckled white and green and resemble a diorite at the first glance. This is confirmed by the microscope:

The large hornblende crystals are of the normal bluish green. They contain abundant reticular inclusions, usually in the centre, of plagioclase and quartz. The plagioclase phenocrysts are an andesine to labrador, with twin lamellas. Small grains of titanite are concentrated in continuous zones. They rarely contain small brown biotite scales. The quartz occurs together with the feldspar, though it is very subordinate.

These dioritic rocks observed in the slice are usually massive. Towards the contact both the schistosity and the amount of hornblende increase. Most of the basic sills of the Askot region are of a similar dioritic mineral aspect.

The basic sills of the same zone further west, at Thal, are somewhat different and more schistose and may be called dioritic amphibolites (Girtia). The hornblende is fibrous, blue-green and partly zonar, with a more coloured olive-green core. A basic andesine occurs, partly altered to klinozoisite. Titanite forms wreaths around the titaniferous magnetite. The accessories are apatite and locally some quartz. In the slice the aspect of the rock is massive. It seems to be somewhat more basic than the usual dioritic sills.

Here it may not be out of place to mention also the amphibolitic sills of the sedimentary series, usually found between the limestone and the quartzite.

In the tectonical description a sill was mentioned between limestone and quartzite north of Badolisera. It is a highly altered diabase. The lath-shaped plagioclase is obliterated by the formation of epidote and zoisite. The sporadic clear andesine may have been formed later. An almost coloured xenomorphic hornblende is present, together with rudiments of uralitized augite. Tourmaline of a dirty violet pleochroism arrests attention. It may have been concentrated along cracks in the shape of tiny layers.

West of Bans is another basic sill of 20 meters at least, the aspect of which recalls those of the crystalline zone of Askot. It may be called a quartz-bearing dioritic amphibolite. The hornblende is ragged and slightly yellowish green. The plagioclase is almost entirely transformed to epidote and klinozoisite. Here too, the titaniferous magnetite is bordered by leucoxene and titanite. Quartz is distributed in patches. The relative abundance of quartz contrasts with that of the amphibolites of Askot. However, the basis of the rock is dioritic or quartz-dioritic. The dioritic aspect is more easily recognized macroscopically than from the slice.

c) The Crystalline Zone of Baijnath

This zone corresponds tectonically to that of Askot. Apart from Bageshwar, the thrusted syncline pitches and widens towards the west. Correspondingly, the granite-gneisses and ortho-augengneisses south of Gwaldam much resemble those of Askot or are even identical. Besides this, the basic rocks are also found again. The marginal granite-gneiss of the granite north of Sirkot, and the contacts of gneiss with mica schists and quartzite are joined to, or interbedded with, basic sills. Also here the rocks are mainly dioritic. The main sill of about 200 meters thickness (Fig. 35) is not uniform. Between massive zones of dioritic aspect are green dense layers rich in tourmaline phenocrysts. The latter rock is a fine-grained tourmaline-epidote-amphibolite. An ordinary tiny green hornblende is ragged in confused distribution. The rare plagioclase is so much altered to clinozoisite that it can no longer be determined. Epidote forming rather large grains is distributed in nests. The tourmaline is almost dendritic and zonar, gray outside and ink-blue inside. It may be a secondary mineral.

The more dioritic parts of the basic zone of Sirkot correspond to a normal amphibolite The hornblende is zonar. The outside colour is more intense; the birifringence and the angle of extinction are lower than at the core. The oligoclase-andesine is partly altered to clinozoisite. The plagioclases cause a slightly ophitic structure. Quartz is subordinate.

Beside these massive rocks are schistose zones enriched with hornblende in layers. The magnetite, otherwise patchy and relictic, is distributed in trains along those of the hornblende. The plagioclases with their abundant inclusions are roundish and recall somewhat a poikiloblastic, prasinitic texture. Together with the hornblende also chlorite in the schistose layers is observed.

The original rock of the basic sill of Sirkot was mainly a diorite with more basic, diabase-like streaks which are now represented by the fine-grained epidote-amphibolite.

d) The Basic Zones of Alaknanda Valley

The wide zones of green schists of Karnaprayag are macroscopically not recognized at once as of basic igneous origin. The conclusion is the result of microscopic study. The lath-shaped ophitic plagioclase is conclusive. Layers of amphibolite are less frequently recognized macroscopically in the very fine-grained rocks which may reach a thickness of 200 meters or more (Simli).

The fine-grained parts are determined as epidotic amphibolites. The hornblende is xenomorphic, ragged and irregular, of olive-green to blue-green pleochroism. Usually the chloritisation is chiefly confined to the horders. Curiously enough the plagioclase is an albite-oligoclase and usually lath-shaped. It may have been originally a more basic type as suggested by the abundance of epidote. The latter generally forms small grains. The larger individuals are yellowish pleochroitic. Titanite too is present, together with plagioclase. Calcite, as an accessory, is considered as having been formed from the more basic plagioclase. Quartz is very subordinate. The abundant chlorite is a secondary product of the hornblende. The latter characterizes macroscopically the schistose parts of the fine-grained rocks and hides the amphibolitic origin.

The coarser-grained rocks are more easily recognizable as epidotic amphibolites. They usually form layers in the fine-grained rocks of similar mineralogical composition. The hornblende is more homogenous and less pleochroitic. The oligoclase stipulates the ophitic rock-character and frequently includes hornblende. The epidote, in large grains, is idiomorphic and zonar. Chlorite is still abundant. In this case too the epidote and calcite may have been formed of basic plagioclase. This conjecture would account for a diabasic origin which is also suggested by the ophitic texture.

Two kilometers north of Karnaprayag, another distinctly amphibolitic sill is crossed on the pilgrimage trail along the Alaknanda river (Pl. IV, Section 7a). It is bedded between finer-grained schistose chloritic rocks. The microscope reveals a titaniferous amphibolite. Its large xenomorphic and somewhat leucoxenitised titanite is formed around titaniferous magnetite. The plagioclase is almost exclusively replaced by clinozoisite and sericite.

The huge basic series of Karnaprayag borders on the north side a minutely folded series of dark clay slates with intercalated quartzitic layers. The slates are microscopically recognized as graphitoid-bearing chlorite-sericite schists. The green pleochroitic chlorite, the sericite and quartz occur in a similar quantity. The graphitoid is equally distributed in fine grains. A bluish tourmaline is found as an accessory. Even the minute folding is visible under the microscope.

Further amphibolitic sills are encountered between Nandaprayag and Chamoli, usually at the contact of the quartzite and the crystalline rocks. In contrast to those of Karnaprayag, they

are recognized at once as amphibolites. Good outcrops occur on the trail north of Nandaprayag, also below the gneiss, above and within the quartzite of Chamoli, at a dip of 45° to S 30° E. Finally, at the mouth of the Birehi river, an amphibolite also underlies these quartzites, separated from them by augengneiss. This latter amphibolite is different from those of Karnaprayag and even macroscopically of a dioritic aspect. According to the high content of quartz, it has to be defined as quartz-amphibolite and probably derived from quartz-diorite. The rock from the lowest part of the Birehi Valley shows under the microscope abundant hornblende of intense pleochroism: X = yellowish; Y = olive-green; Z = blue-green. The extinction is Z/c = 18°. Quartz predominates over the plagioclase in such a way that the latter, an albite-oligoclase, is almost an accessory mineral. The rock, in parts with scanty feldspars, might even be called a quartz-amphibolite schist. The feldspar is replaced by clinozoisite and epidote. Joined to the hornblende is an olive-brown biotite. Magnetite is another accessory mineral. The schisty character of the rock is caused by parallel textured hornblende.

Layers of "Hornblende-Garbenschiefer" are found within these amphibolites. This name is not quite correct, inasmuch as feldspar is still present. The large sheaf-like idiomorphic hornblende is intensely coloured: X = pale yellowish green; Y = dark green; Z = intensely blue-green. The extinction Z/c is about 17°. The hornblende stalks are bedded in layers of chlorite and quartz. They also contain rather long plagioclase, determined as acid andesine. The twin lamellas are fairly well defined. Rutile is present in layers and as an inclusion of hornblende.

The above described quartz-amphibolite was only found on the southern border of the Pipalkoti limestone region. Most of the amphibolitic sills from Chamoli to Nandaprayag are also at the contacts of the crystalline schuppen with quartzite. Similar observations will be described of the contact zone formed by the Main Central Thrust.

THE CENTRAL HIGH RANGE

(Nampa—NandaDevi—Badrinath)

Of this range, forming the highest peaks of the Central Himalaya, we have in part studied the three above named massives.

The Nampa Group (Nepal)

(chiefly by A. GANSSER)

This is the least known of the three main elevations. On the original sheet 1″ = 1 mile Nr. 261, the highest mountain indicated as 23352′ at 30° lat. N and 80° 58$^1/_3$° E is called Nampa, as we heard it by the natives of Garbyang. On the more recent map Nr. 62 B, 1″ = 4 miles, the same summit is given as 23399′ and called Api. As the top is a flat ice sheet, and nobody has ever climbed this mountain, these figures cannot be accurate. We have therefore called and figured the mountain under the name of Nampa and given it the rough figure of 7100 meters (30, phot. Nr. 60, 79, 81).

The western part of this massive has been mapped more or less correctly by the Survey of India, whereas the South, East and North-East remained practically unmapped and unknown. The sketch-map Fig. 10, p. 85 and the panorama Pl. II of "Thron der Götter" give an idea of the magnificent mountains and crests on the eastern and north-eastern side of the Nampa. They form an insurmountable barrier between the main part of Nepal and its north-eastern corner, which is only accessible from Kumaon or Tibet.

a) Tectonics

The whole Nampa group is dominated by a regional northern to north-eastern dip, usually of 30—40°. The large Garbyang series which forms the highest summits also is monotonous. The basis of the highest summit, the Nampa 23399′ (7135 meters), is formed of the zone rich in lime-silicate and pegmatite dikes, as seen on the SW side of the Nampa in the background of the Api glacier (see chapter petrology and photo 6 Pl. VII). The boundary to the Budhi zone is well seen on the sharp peak 19919′ (Fig. 44).

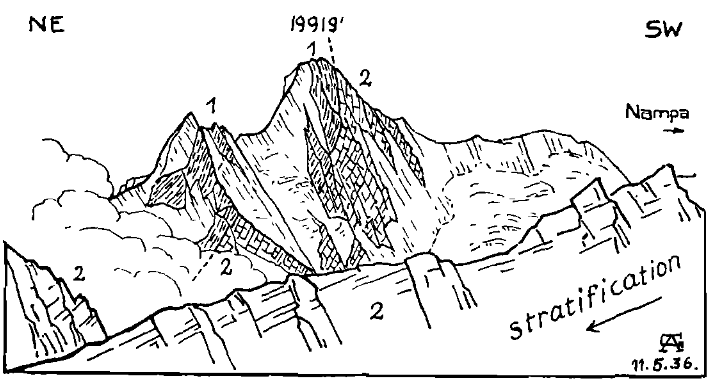


Fig. 44. The Budhi Zone in the Nampa Group.
1 = Zone of biotite-psammite-gneiss and lime-silicates; 2 = Phyllitic schist of the Budhi Zone with biotite porphyroblasts.

The large ice cuirass of the Nampa completely covers the rock. It seems that the Budhi Zone passes over the summit. The rocky walls on the NNE

side do not show any more pegmatite dykes, one on Nampa glacier Nr. 2 excepted (Fig. 45 and 49).

At the basis of the Garbyang series which forms the peaks around the Nampa Valley, a green chloritic layer of about 50 meters is found. It could be followed from above Budhi towards ESE over the peak 19919' to the NE walls of the Nampa and its eastern side. It is taken as the basis of the Garbyang series, while the Budhi zone is regarded as the reduced Martoli division.

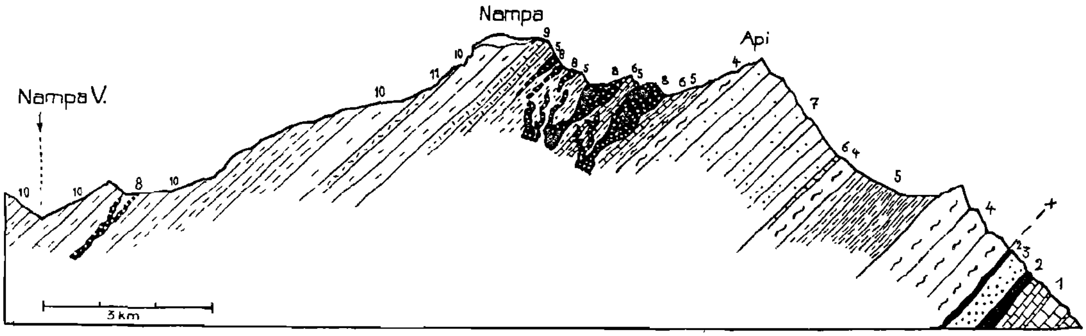


Fig. 45. Section of Nampa (7135 meters).

1 - 3 = Sirdang zone:
1 = slates and limestone;
2 = amphibolite;
3 = quartzite;
4 = Injection-gneiss (Kali zone a);
5 = Paraschists with garnet (zone b);
6 = Lime-silicates (zone c and f);
7 = Highly metamorphic quartzite with kyanite (zone d);
8 = Aplitic granite, pegmatite and tourmaline-aplite (zone f);
9 = Budhi schists (zone g);
10 = Garbyang series (zone h);
11 = Green schists of Garbyang series.

In the background of the Nampa Valley, and especially in the easternmost part, the Garbyang series is banded by minute repetitions of greenish and yellowish layers similar to varves. In the quartzitic limestones diagonal bedding and primary folds, discordantly overlapped by undisturbed strata, were also observed, probably caused by subaquatic sliding. Though frequently only of the size of some centimeters, such occurences are widely distributed.

In the region of the Nampa glacier Nr. 4, some quartz dykes were found containing copper ore (Fahlerz). The glaciers Nr. 3, 2 and 1 carry also rocks from deeper zones. Aplite dykes occur, but quite exceptionally, as high up as the Garbyang series, such for instance as that on the lower glacier Nr. 2 (Fig. 49 and petrologic description).

b) Glaciation

Api Valley

We called the valley on the west side of the Nampa the Api Valley and its glacier the Api glacier. It fills the space between the Nampa and its southern lower neighbour which may be called Api (30, photos Nr. 46 and 60).

The valley is partly filled with old moraine, which is so much hardened that it sticks out on the steep slopes up to nearly 200 meters above the actual glacier brook.

The first terminal moraine of recession forms a wall at an altitude of 3670—3700 meters (phot. 50, Pl. XIX). The next one is from 3850--4050 meters. At an altitude of 4100 meters, miniature lakes are found in the block field, pointing to ice below. Here is the lower end of the actual Api glacier.

Bad weather prevented us from following the Api glacier upwards for more than about 4 kilometers towards SSE. Not far from there, the valley turns round, coming from SW (Fig. 46)[1].

[1] The map sheet 62 C, 1" = 4 miles shows a long ice crest from "Api" 23399' towards SW called Api Letch, where the glacier flows northward in a deep valley.

In this upper part the glacier, to a great extent, is fed from the hanging glaciers on the NW slope of the Nampa, and to a lesser extent from the side glaciers from the SW side. The sharp moraine crests of the latter are deviated by the main glacier, on the left side of which they continue further downwards (phot. 6, Pl. VII).

Part of a large moraine wall is left some kilometers above the end of the Api glacier, on its left side, 100—150 meters above the corresponding part of the actual ice, at 4400 meters. There are, thus, three steps of moraines in the Api valley, at 3700, 4050 and 4400 meters of equal intervals.

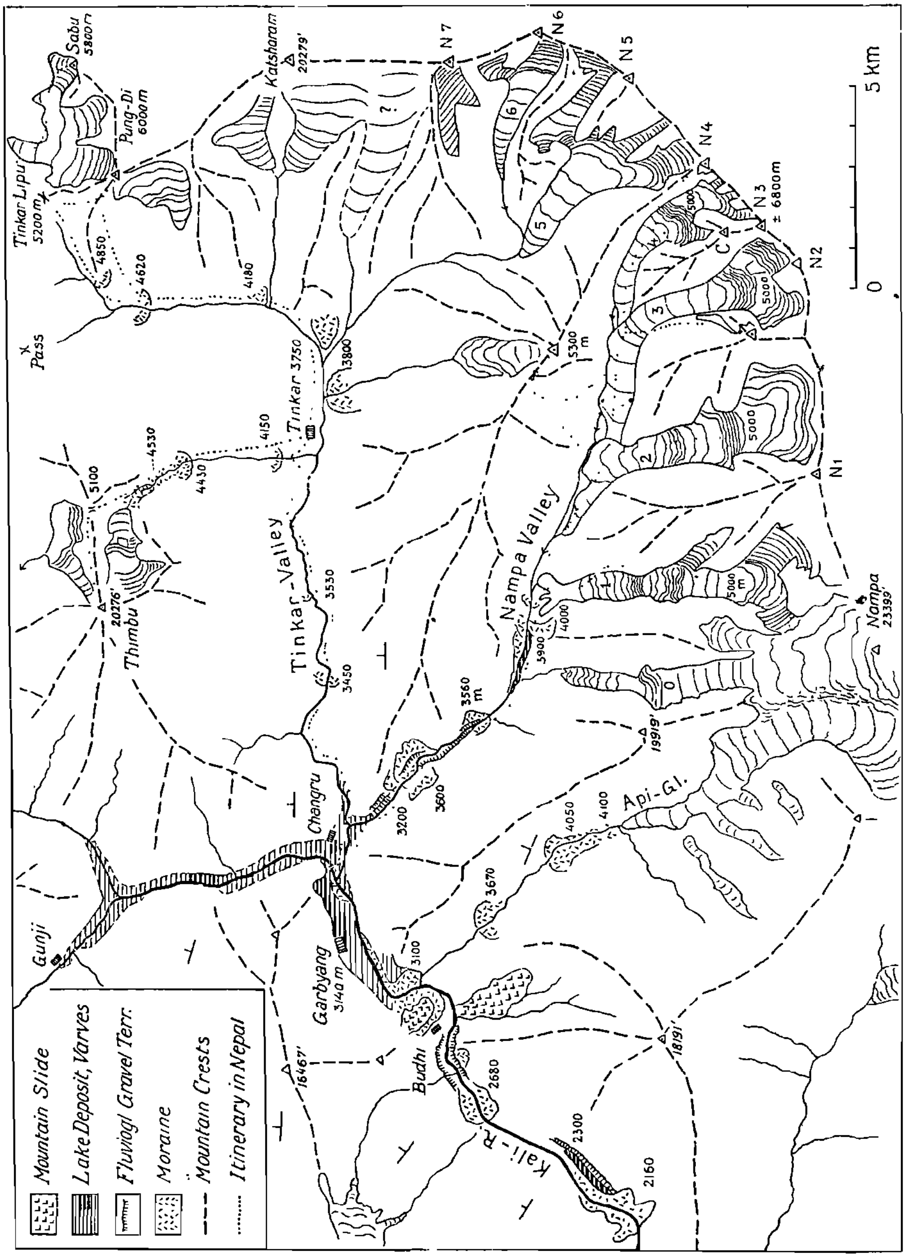


Fig. 46. Sketch-map of the glaciation in NW-Nepal (mainly by A. Gansser).

Nampa Valley

In regard to glaciation, the uninhabited Nampa Valley is one of the most interesting of the Central Himalaya. Being, however, in a forbidden country (Nepal), the observations had to be made in a hurry.

Former Glaciation

Similar to the Api glacier, three main moraine stages of recession were found (Fig. 46).

Near the entrance to the Nampa valley, above its junction with the Tinkar valley, the sediments of the former Garbyang lake (gravels and varves) are transgressive over the lowest and biggest moraine.

This moraine begins at 3200 meters and reaches 3600, thus forming a rampart of about 400 meters height. It corresponds to the moraine stage of 3670 meters in the Api valley.

Attached to the lower part of this moraine is a second stage of nearly horizontal gravel terraces at 3380 meters, which extend 2—3 kilometers farther backwards, up to the end of another moraine of recession at 3560 meters. This second recession stage is of secondary importance; the glacier was already reduced in thickness.

In the interval of this middle stage and the next higher one of 3900 meters, which reaches on the right side an altitude of 4000 meters, the moraine of the main valley is replaced by those of the southern side valleys. This division of the Nampa valley is of special interest on account of the following observations:

The moraines of 3600 and 3560 meters have dammed up a lake in which were deposited gravel, sand and clay, similar to those of Garbyang. Below the moraine of 4000 meters towards west, the Nampa river has cut out horizontal varves in repetitions with sand and gravel, the latter continuing valleywards as far as the moraine of 3600 meters. These lake deposits reach down to the rock-ground. They are covered in their middle part with moraine of 100 meters thickness (Fig. 47).

This covering moraine belongs to the first large side glacier, which comes down from the summit of Nampa and ends upward in seracs above a rock-wall of 300 meters height. It is a fact of special interest that it was the side glacier which advanced over the lake gravels at a period when the main glacier did not reach any longer so far. After its three stages of recession the main glacier retreated behind the great moraine of 4000 meters. Then followed a new advance, but only of the side glaciers, down into the main valley, following it even for a short distance.

Exactly the same phenomenon is found further up on the present glaciers.

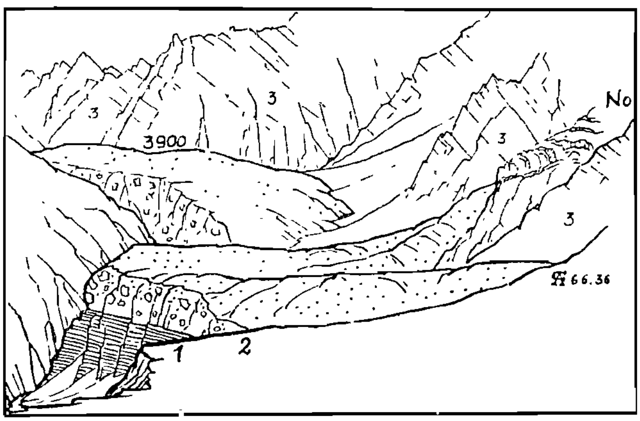


Fig. 47. The Moraine of a Side Glacier covering the Lake Deposits of the Nampa Valley.

1 = Gravel, sands and clay with varves; 2 = Moraine of the side glacier from south; No = First northern side glacier of the Nampa (numbered O as it does not reach the main valley) 3 = Garbyang series, Cambrian. In the background is seen the moraine of 3900—4000 meters of the main Nampa glacier.

Present Glaciation

In the hitherto completely unknown Nampa valley four southern side glaciers were found, numbered 1—4 from W to E, on Fig. 46, while the main glacier no more exists.

All these glaciers are covered with upper moraine up to about 4500 meters where the ice fall (Gletscherbruch) begins. On all the four glaciers, this ice fall is at the same level from 4500—5000 meters. Above it follows a glacial terrace of 5000 meters, which may correspond to the surface of the main glacier in Pleistocene time. The block-covering from above begins in a striking way on all four glaciers, just below the ice fall, although there is no visible supply of scree from the sides.

Glacier Nr. 1 deriving from the circus (Kessel) of the east wall of the Nampa flows regularly into the main valley where it expands undisturbed by a former main glacier on the almost level ground, so that the glacier becomes subdivided into three branches with intermediate moraines (Fig. 48).

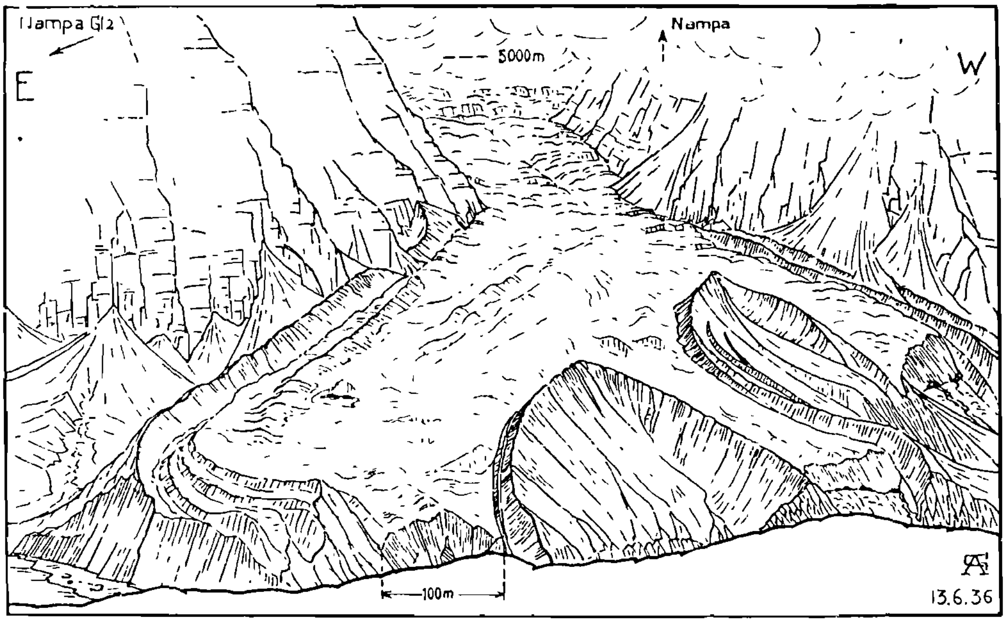


Fig. 48. The Termination of Nampa Glacier Nr. 1.

The glacier ends at 3770 meters and nearly reaches towards west the big moraine (4000 meters) of the former main glacier. It is this moraine which dammed the present side glacier and caused also its spreading, with a branch valley-upwards.

Glacier Nr. 2 does not at present reach Nr. 1. Its snout is similar to that of Nr. 1, although it is slightly deviated by Nr. 3 inspite of the duplication (Phot. 57, Pl. XXI).

Glacier Nr. 3 flows uniformly down to the main valley following it until becoming overridden by Nr. 2. The large right lateral moraine of the latter traverses the whole glacier Nr. 3, which is about 30 meters lower than glacier Nr. 2.

In exactly the same way, glacier Nr. 4 is overridden by Nr. 3. The right side moraine of Nr. 3 crosses the whole glacier Nr. 4, and here too the underlying glacier is about 20 - 30 meters lower. The glacier river of Nr. 4 leaves the glacier for a short distance and disappears again below the riding glacier Nr. 3.

The glacier river of Nr. 3 has a narrow passage between the rocks and the ice of Nr. 2. Both glaciers, Nr. 3 and 4, flow down towards north and then turn to west. The main glacier thus does not exist any more. In its place are the tongues of the side glaciers of which the western ones override the eastern ones.

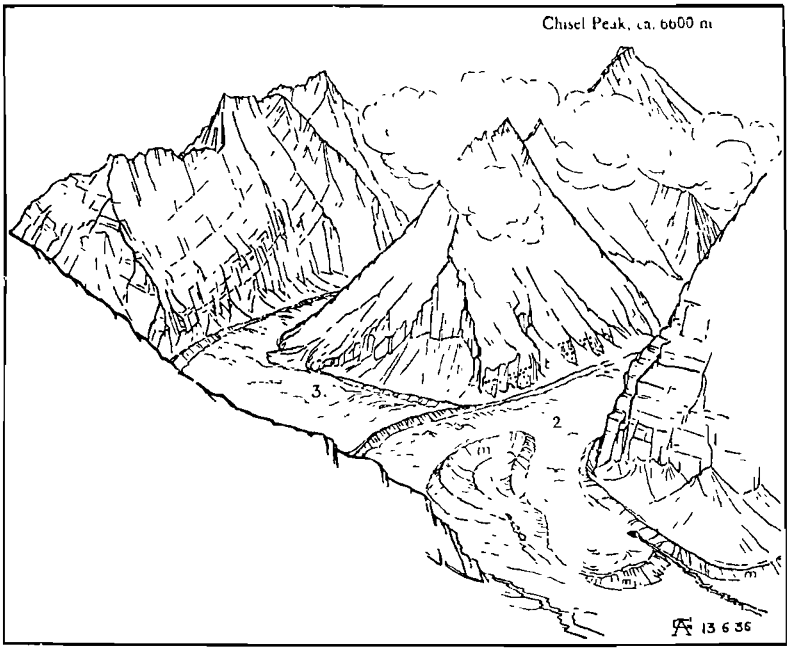


Fig. 49. The Nampa Glacier Nr. 2 overriding Nr. 3
t. .... = Tourmaline-aplite; m = Moraine. The rock walls are made of the Garbyang series.

The large lateral moraines of the different glaciers do but rarely reach far out into the valleys. Usually the avalanches of the exceedingly steep slopes destroy the ramparts or fill them up, forming cones from which the glaciers are fed (Phot. 57, Pl. XXI). Where the lateral moraines are preserved, they form a crest up to 40 meters high, sloping off abruptly from the glacier, whereby the surface of the glacier is always more elevated than the outer foot of the moraine. There, small lakes may be found, especially along the left lateral moraines where they turn into the main valley, and at the junctions, where the left lateral moraine of the underlying glacier pushes on the right lateral moraine of the western riding one. Only in this place where so much snow with scree is brought down the glaciers seem to touch directly the side walls of the valley.

On the glacier side of the lateral moraine, the crest is subdivided. Inside the highest crest follow several more subordinate crests of decreasing height. The following striking observation was made:

In the lower part of Nampa glacier Nr. 1 there are 4 crests clearly recognised on the right side of the expanding glacier, caused by three periods of recession and stagnation. The moraines of glacier Nr. 2 (Phot. 57) have 3 crests at the most, and Nr. 4 usually shows only one undivided interior face of the lateral moraine. It is the highest one, where the glacial changes had less influence.

The Nanda Devi Group (Kumaon)

Nanda Devi with its two peaks of 25645′ (7820 meters) and 24391 (7435 meters) is the highest mountain of the Central Himalaya. It was ascended on August 29th 1936 by the Anglo-American Expedition. On the geological map of the Himalaya (in 8, 1934) the Nanda Devi and Nanda Kot groups are still erroneously indicated as "unclassified gneiss".

Eastern Section (by A. Gansser)

a) Tectonics (Pindar-Traill Pass)

In order to explore the structure of this highest summit, the so-called Traill Pass on the crest between Nanda Kot and Nanda Devi was traversed, departing from Martoli (Pl. III, section 6c).

This village is situated on a gravel terrace more than 200 meters above the Gori river. On its western side a former epigenetic gorge was found, filled in with gravel.

From Martoli towards west, the Lwanl Gadh offers excellent exposures up to the unnamed glacier which descends from the NE side of the Traill Pass and is fed by the main side glaciers, one descending from Nanda Kot, the other from the eastern summit of Nanda Devi.

The surrounding of Martoli is situated on the Martoli series, made of somewhat folded sericite-phyllite with small quartz veins, which cross the stratification in the direction of the cleavage, at an angle of about 60°. Quartzitic and always sericitic layers are also interbedded. The lower part of Lwanl valley follows the western strike with a variable dip. West of Martoli, the dip is towards south, then SSW.

Towards the glacier which will be called Lwanl-glacier, the valley turns towards SW and the strike to WNW. At the glacier tongue, at 4200 meters, the dip is to N and NNE. The phyllites there are more quartzitic and somewhat calcareous, recalling the series at Garbyang. Both sublime summits, Nanda Kot and Nanda Devi, are made up of the little metamorphic sedimentary Martoli series.

Above the western side glacier rises more than 3000 meters high the immense eastern wall of the eastern Nanda Devi Peak. Inspite of ice and much fresh monsoon snow, the general structure could be plainly observed. Nanda Devi forms a wide syncline of carbonatic quartzite with sericitic phyllite layers. Two aplitic dykes were recognized on the eastern summit exclusively. All rock types are assembled on the moraine below the great rock wall (Fig. 50).

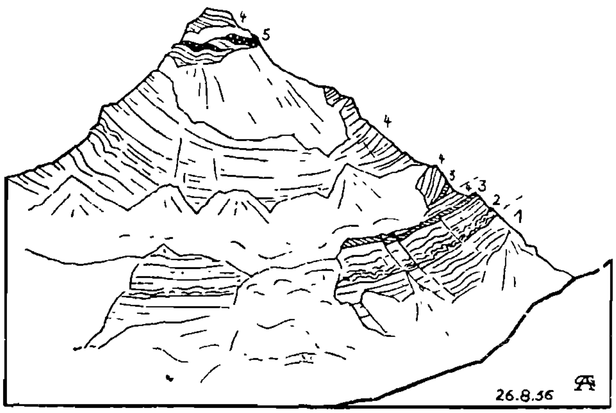


Fig. 50. The Structure of Nanda Devi-East.
1 = Gray quartzite with sericite quartzite; 2 = White quartzite, locally folded; 3 = Dark slates (?); 4 = Sericite phyllite with yellowish carbonatic and dolomitic quartzitic sandstone layers; 5 = Dykes of tourmaline aplite.

Only on the south side of the Traill Pass, real metamorphics occur. Nanda Devi is thus not made of "unclassified gneiss", as mapped by GRIESBACH and copied in later publications, but of the sedimentary Martoli series, which is here of a similar facies as the younger Garbyang series.

Similar conditions prevail at Nanda Kot, which, on account of the ESE strike, is built of somewhat deeper and more metamorphic strata, corresponding to those of the Traill Pass, which carry already biotite porphyroblasts. (See petrographic part.)

On the eastern Lwanl glacier coming from Nanda Kot, large blocks of conglomerate were found. It consists of a greenish quartzitic groundmass in which globular to oval pebbles, of a palish pink quartzite, up to the size of a head are embedded. They are partly somewhat stretched. According to the size of the blocks, the corresponding layer must be at least 10 meters thick. The conglomerate recalls somewhat the Ralam conglomerate which belongs to a lower series. Nothing could be seen of the conglomerate on the western rock walls of Nanda Kot, not only because of the ice cuirass, but also on account of the fresh snow cover.

The proper metamorphosis begins in the steep rock-scarp above the Pindari glacier, south of the Traill Pass. Small scales of biotite are found in the quartzose sericite phyllite. When they are getting larger and more frequent, we come to the Budhi schists with their biotite porphyroblasts. Then follows the garnet. The quartz veins carry stalks of kyanite. Feldspar appears and leads on to the biotite-psammite gneiss, which is pierced by pegmatite veins (see Petrology).

The whole large series of gneiss, with intercalated metamorphic quarzite, reaches down to Loharkhet. The thickness, according to the regular dip of 30° to NE, is about 10 kilometers.

At Loharkhet, the mighty augengneiss, after an intercalation of some meters of amphibolite with little plagioclase, overlies conformably a quartzitic series of about 1100 meters. The quartzite forms the precipice to the upper Sarju valley. It is remarkably pure and well-bedded,

dipping 35° to NE. The basis is more greenish and contains here and there thin layers of fuchsite.

With a sharp boundary the quartzite overlies a green chlorite schist, derived from a basic sill, underneath which follow slightly metamorphic argillaceous slates. The latter pass downward into calcareous shales.

The dip of 35—40 towards NNE is shown on isolated thin quartzite intercalations. The contact of the chlorite schist and the slates is not exposed. The occurrence of basic sills between slate and quartzite and between quartzite and gneiss recalls the Kali section on both sides of the zone of Sirdang.

About 5—6 km south of Loharkhet, the calcareous slate is underlain with a sharp boundary by yellowish dolomite with sporadic layers of sericite schists. The basis is more massive, gray blue and banded, the yellow bands becoming subordinate. The main constituent of this large series is dolomite. Towards the basis the minutely banded dolomite is dark gray and intensely folded in detail, which may partly be of syngenetic origin (subaquatic sliding?).

The underlying strata, dipping 45° to NNE, are mainly tabular limestones, recalling and apparently being Kroì. More towards south, the whole series steepens. Below the huge carbonatic series of about 3 kilometers thickness follow with a sharp boundary about 100 meters of black, somewhat rusty weathered slates with some sericitic streaks, dipping 60° to NE. On the small hill north of Kharbagar, where the trail cuts off a bend of the Sarju river, finely banded yellow and gray dolomite is again found. Apart from this hill, where the strata are vertical though still of the same north-western strike, the dip is towards SW, as seen in the direction of the river coming from Sama. We are therefore facing here another peculiar anticline in the shape of a fan opening downwards. Indeed, the black slates are repeated with a dip of 60° to SW, and thereupon again follows the huge series of dolomite and limestone, with a south-western dip down to beyond Kapkot.

Glacial Observations

Climbing over the Traill Pass, two main glaciers were traversed, the Lwalu glacier on the north and the Pindari glacier on the south side.

The glacier which we called after the Lwalu valley has its collecting ground at Nanda Kot and Nanda Devi-East. The snout of the branch from Nanda Devi remains 2—3 km behind the main glacier. The almost flat interval is at 4300 meters. The termination of the main glacier is 5—6 km farther NW at 4200 meters. It is therefore almost flat in its lower part. Though interrupted by the Nanda Devi branch, it is still in connection with that from Nanda Kot. The collecting snow field is very large. This explains its north-eastern continuation over that flat space of the valley. This lower part is of special interest: it is framed by large sharp lateral moraines attaining a height of 100 meters. The ice is almost 100 meters above the present valley bottom and flows like a river between the dams. At the snout (4200 meters) the glacier river appears about 20 meters above the valley bottom, showing that the ice is swimming 20 meters high upon the own ground moraine (Fig. 51).

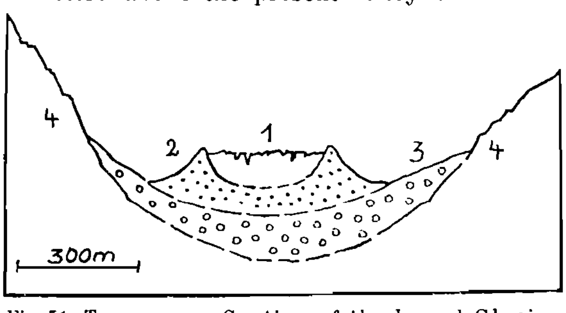


Fig. 51. Transverse Section of the Lwanl Glacier. 1 = Glacier ice; 2 = Sub-recent moraine; 3 = Old moraine and gravel; 4 = Rock (Martoli series).

The old topographic map 1″ = 1 mile, though remarkable for the time, is very inaccurate in this region, also regarding the famous Pindari glacier. It does not convey its proper position and shape.

The Pindari also has two main collecting grounds: the westward one is the circus to-

wards the Traill Pass, the eastern one is on the south side of Nanda Kot. The end of the Pindari glacier frequently visited by tourists, was found at 3700 meters (barometric).

In the Pindar valley, as well as in the Lwanl, no distinct older moraines were found. The last moraine-like deposit of the Pindar valley was recorded about 3 km north of Kati, at 2300 meters. This stage may correspond to that of the Kali at about 2150 meters.

Western Section (Dhauli-Rishi Ganga)

a) Tectonics

On the north side of the Kuari pass (p. 45) the Dhauli Ganga has formed a deep valley in the shape of an arch with its convex side turned to the south, first making a transverse section and then cutting a longitudinal valley down to its confluence with the Alaknanda at Joshimath-Vishnuprayag. The rocks are mica schists with quartzite layers, alternating with real biotite gneiss which becomes predominant towards Joshimath. The dip is 20° to N and NNE at the Kuari pass and gradually steepens up to 45° towards N. (Fig. 37, 52.)

About 2 km below the mouth of the Rishi Ganga, the trail passes over a spur of gneiss with muscovite, biotite and kyanite, together with layers of marble and limesilicates dipping 38° to E 25 N.

In the Rishi gorge the mica schists, full of garnet, still dipping 30°, strike to S 30 E, and on the north side of Nandakna, already seen at a long distance, the strike is even S 15 E. The strike from Joshimath forms thus a wide arch, turning from nearly east to nearly south. Joshimath lies in the prolongation of Nandakna.

b) Morphology

The lower Dhauli and the Rishi gorge are interesting on account of their morphological features.

Mountain Slips

All along the north of the Kuari pass, the Dhauli, in its north-western course, has been forced to the right, so that this side of the valley is formed of steep walls. This is not caused only by the dip of the gneiss and the mica schists towards NE, but especially by an almost general slipping of the left valley side on the micaceous bedding planes. Joshimath is situated on a slope of blocks which extends 5 kilometer to the SE.

The next mountain slide is crossed by the same valley trail at Dhak (Topogr. map 53N, 1" = 4 miles, 1936).

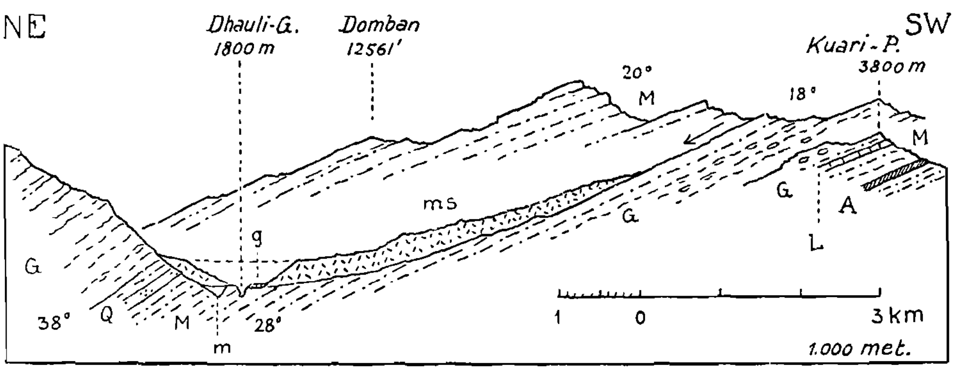


Fig. 52. The Kuari Mountain Slide.
G = Gneiss; M = Mica schists; Q = Quarzite; A = Amphibolite; L = Marble; ms = Slided scree; m = Moraine (?); g = Gravel terrace.

The largest and longest landslide has its origin on the mountain crest at 4000 meters, east of the Kuari pass. We shall call it the **Kuari Slip**. The length from S to N is 8—10 kilometers, the width up to 3 kilometers. The average thickness being estimated at 150 meters, the volume would be about 2,3 cubic kilometers.

This Kuari slip is partly covered with fir timber and in places is cultivated and inhabited. Several small villages are situated on the stream of scree. Besides the artificial terraces on which wheat, barley, mill, corn, amaranthus are cultivated, there are also indications of river terraces along the Dhauli. As seen at a distance, it further seems that there is moraine below the slided material. The whole appearance is that of a pre-historic and perhaps inter-glacial slide.

Lack of time prevented us from climbing over the right side of the valley. It looks as if the terraced green triangular ridge which rises nearly 300 meters above the right side of the Dhauli were forming the frontal part of the Kuari slide (phot. 53, Pl. XX). There, part of the old valley is filled with moraine and slided scree. In cutting accross the great barrier wall, the river did not strike its old way again, but has cut an epigenetic gorge into the mica schists and quartzites above the bridge of Tapoban. The filling of the old valley is especially suggestive as seen from the east side of the frontal wall of the slide, shown in Fig. 53.

Farther up the Dhauli, more slides, partly mixed with moraine, come from the southern valley side. On the last one we stepped over is situated the village of Lata (2350 meters). Looking towards the N from the Lata crest, we noticed in the Dhauli a fjordlike sandy valley bottom, of several kilometers length. It must be a lake filling, caused by another mountain slide or by a late pleistocene moraine.

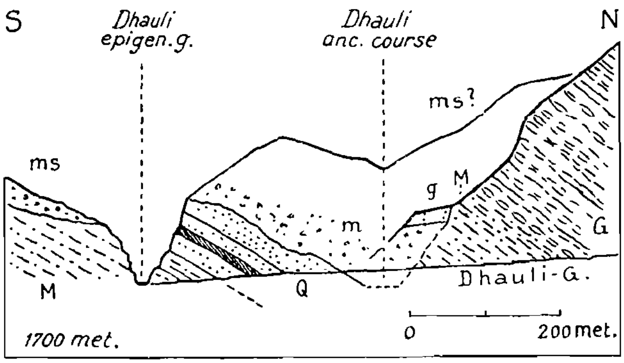


Fig. 53. The epigenetic Gorge of the Dhauli seen from the East.

M = Mica schists; Q = Quartzite with a layer of chloritic amphibolite; G = Gneiss; m = Moraine (?); g = Gravel terrace; ms = Mountain creep.

Moraines

The Rishi Ganga forms the only issue of the great Nanda Devi glacier basin. We thus expected to find moraines farther down the valley than usual. However, the intense water erosion has removed the greater part of the former glacier deposits. This is the case along the Dhauli up to Tapoban. Above the bridge of this village, along the trail on the left side of the river, several outcrops occur, of a material resembling ground moraine. But we looked in vain for striated pebbles. In places material is hardened and sticks to even vertical rock sides.

Just above the mouth of the Rishi Ganga, which carries about half as much water as the Dhauli, the remains of a great barrier of about 200 meters height cross the Dhauli valley. It is formed of gneiss on the left and of moraine or transported slide material on the right side of the Dhauli gorge. (Fig. 54).

We are again in presence of an epigenetic gorge, similar to that 4—5 kilometers farther below. The block material is heaped up at the corner of the former Dhauli and Rishi glaciers.

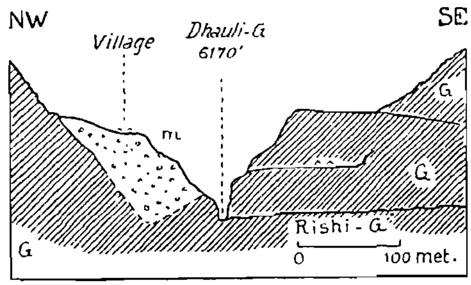
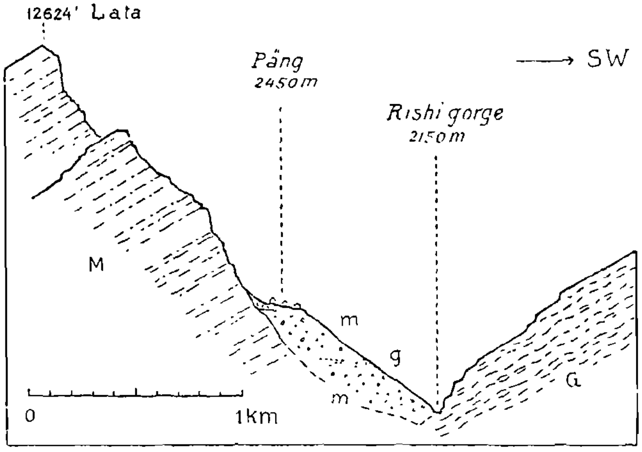


Fig. 54. The Dhauli Barrier above the Mouth of the Rishi Ganga.

G = gneiss; m = moraine (?).



Finally, below the walls of Lata 12624', the north side of the Rishi gorge is formed of moraine up to 300 meters above the river, with an intermediate gravel bed (Fig. 55). As we found such an interval within the moraine deposits also in other valleys, the gravel may be regarded as interglacial, or interstadial within the Würm period.

Fig. 55. The Pleistocene Glacial Deposits in the Lower Rishi Gorge. G = Gneiss; M = Mica schists with garnet; m = Hardened ground moraine; g = Gravel layer.

The Badrinath Group

The Upper Alaknanda

a) Tectonics

We first continue the description of p. 52 by means of section 7b Pl. IV. This part of the section is a projection towards the W according to the average strike above Joshimath, which is mainly E–W.

Descending to the gorge at Vishnuprayag, the gneiss is exposed below the slided block field. It is biotite gneiss with minute fluidal folding, of the Darjeeling type. Above it, also regionally dipping 45° to N10E, follows a repetition of highly metamorphic mica schists and paragneiss with injections, of the following approximate thickness:

a) 1200 meters of chiefly mica schists with garnet;
b) 400 meters of chiefly gneiss;
c) 700 meters of chiefly mica schists with garnet;
d) 9400 meters of quartzite with subordinate mica schists.

With slight changes of the strike, the dip of this enormous mass of well-bedded quartzite[1]) varies from 40—70°. No indications of tectonical repetitions having been found, we are forced to consider it as a normal succession! Only above the waterfall of Kaliankoti, between the two iron bridges, the rock changes into a highly metamorphic sedimentary series with injected augengneiss, characterized by lime-silicates. The dip is 55—65° to N15W.

The next subdivision sets in with a series of quartzites and lime-silicates, injected and interbedded with gneiss and amphibolitic layers. The latter can also be traced on the walls on the west side of the valley by their rusty weathering. This series shows minute zigzag folding.

The two last subdivisions have a thickness of about 1,5 kilometers. The trail following the east side of the Alaknanda now enters moraines. As seen from the distance, on the high walls of the western side, the injected series with lime-silicate layers continues and gradually steepens to a vertical and even over-vertical position, in the shape of a synclinal fan. Its vertical axis, striking W20°S, passes the river below the bridge of Bamani, 1,5 to 2 km south of the temple of Badrinath. There, the succession towards the North is as follows:

[1] J. B. Auden (4) already drew attention to this enormous body. Taking an average dip of 45°, he obtained 32,000' of the "granulitic series" from Vishnuprayag to Painor (= Pandor?).

a) Biotite gneiss and mica schists, about 80 meters, dip 80° to S 30 E;
b) Banded lime-silicates, about 100 meters;
c) Gneiss and gneiss-quartzite, dip 60° to S 25 E;
d) Highly metamorphic sediments with injected gneiss and calc-silicates forming a flat anticline, of 10—20° pitch to W 15 S, thickness about 1 kilometer.

Reviewing the Alaknanda section from the thrusted basal mica-schists and gneisses at Urgam valley up to Badrinath, we find the three following huge subdivisions, of which the first two are apparently in a normal succession:

1) 7,8 km mica schists and gneiss;
2) 9,4 km quartzite ("granulite");
3) about 4 km of injected paraschists characterized by lime-silicate layers.

This latter series, above Mana and thence to the West, becomes to a great extent replaced by granite with aplitic dykes and sills.

b) Morphology

Above the mouth of the Dhauli at Vishnuprayag, the gorge of the Alaknanda not only continues upwards, but even becomes more tremendous. As seen from Joshimath towards the North, the convex walls seem to leave no more room for the river, as if they had been caused by a fault collapse. But the traveller soon finds himself on a well maintained gently rising trail between the shady walls. They exactly correspond to each other on both sides and leave no doubt, that this transverse gorge is also exclusively formed by river erosion. The hard quartzites, for 10 kilometers, seem to have been cut across as easily as the mica schists and gneisses (Fig. 56).

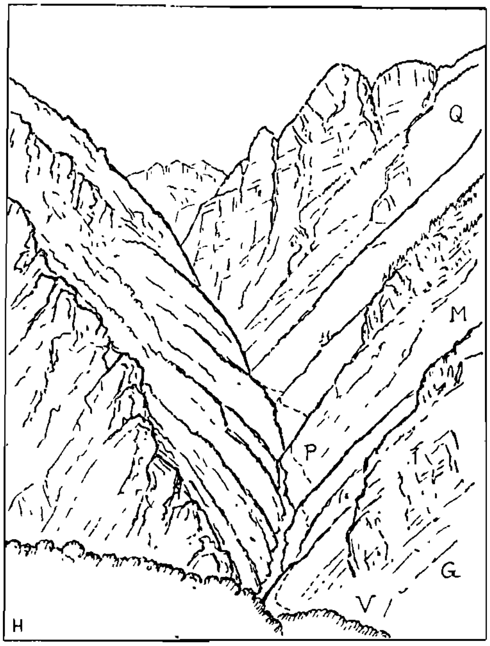


Fig. 56. The Alaknanda Gorge across gneiss, mica schist and quartzite, seen from Joshimath towards the north.

G = Gneiss; M = Micaschists with garnet; Q = Quartzite, V = Vishnuprayag; P = Pilgrimage trail to Badrinath.

The valley widens towards Pandukeshwar. Several small mountain slides have come down from both sides of the valley, and have dammed the river. A flat step about ½ kilometer in length still shows this effect.

Not far above it, 2,3 kilometers from the pilgrims' halt of Pandukeshwar, we reach the terminal moraine which probably corresponds to the alpine Würm stage. The small village of Patri, on the east side of the Alaknanda, lies just below the moraine wall, which seems to pass over to a low gravel terrace. The elevation above sea-level, taken with the aneroid, is 2030 meters. The end of the ice was at an altitude of 2000 meters.

With some interruptions, caused by side stream erosion, the lateral moraine can be followed on both sides along the river. At first the ridge rises more rapidly than the river. Then it runs parallel to it. At 1,5 kilometers from the end, the left moraine is 50—60 meters above the river. Thence the right moraine too is preserved. The trail follows its crest through jungle. On it we noticed a large block of quartzite, with diagonal glacial striation. The valley is still narrow, the two corresponding moraine ridges being only about 250 meters apart. A wall of quartzite in a side valley, coming from the right, shows striation made by the side glacier.

At Lambagar, the quartzite rocks project like a spur towards west and show some striation on the vertical walls. Above the hanging bridge follow a typical ground moraine and

another spur of quartzite with well preserved striation of the main glacier, but over a small space only, at about 30 meters above the river. On the whole, the polish is scarce and poor, although the quartzite would have perfectly preserved it.

Opposite the longitudinal Khiraun valley, the trail makes a curve over the blockfield of a wide mountain slide coming from the east side. It is of the shape of an ordinary fan and seems to be post-glacial. A little farther on follows a moraine hill at about 2530 meters, some 60 meters above the river[1]. It seems to present a stage of recession and to be in connection with the waterfall of Kaliankoti (= Hanuman Chatti), above which extends a level step of the valley-floor (Talstufe).

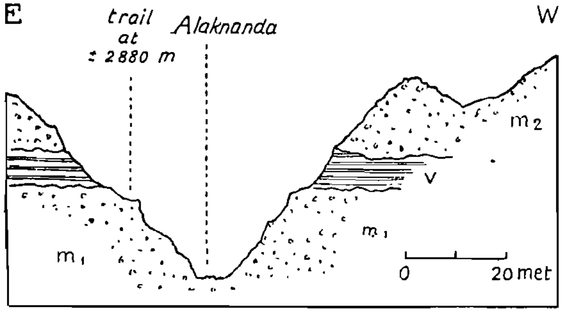


Fig. 57. Varves within the Moraine of the Alaknanda about 2 km south of the Bridge of Badrinath.
m = Moraine; v = sandy clay with varves (lake deposit)

Apart from about one kilometer above the second iron bridge after Kaliankoti, the trail enters into moraine and scree of landslide in which it remains as far as Badrinath.

The moraine reaches about 200 meters above the river. At 2880 meters it is interbedded with horizontally stratified varves of micaceous sandy clay, recalling those of the Kali river. This deposit is about 10 meters thick, and is regarded as an interglacial or interstadial lake deposit (i of Section 7b, Pl. IV and Fig. 57).

Further down no subdivision of the moraine was recognized any more; whereas further up the varves are replaced by gravel with which the former lake, at its upper end, was filled before the glacier again advanced over it.

After an arduous climb in zigzag over the upper moraine, the traveller reaches the great "dam" at Bamanī, 3100 meters, behind which extends for nearly 4 kilometers the flat and widened valley section (Talstufe) of Badrinath.

The little time at our disposal was not sufficient to determine whether the wall of Bamani is a mountain slide or a retreating stage of moraine. It may be both - a slide upon the moraine, similar to that of Garbyang.

The Alaknanda, from Badrinath (3080 meters at the bridge) to Mana (3170 barometric), i. e. on 3,5 km in a straight line, has only a gradient of 5,5%, whereas below the dam of Bamani it is about 15% on an average over a length of 3 kilometers, and even much more directly below the dam.

Another great barrier, cut across by an epigenetic gorge, follows above Mana.

The transverse valley of the Alaknanda, similar to that of the Kali, is thus far from being balanced. Its course is irregular and wild.

Probably the dam of Bamani once formed a lake during a short period. It was filled up with gravel (Stauschotter). North of the bridge of Badrinath, the terrace of coarse gravel reaches about 30 meters above the river. The pebbles of gneiss are usually of the size of a head. At the bungalow, on the west side of the river, the gravel is covered by moraine. The widened valley of Badrinath, moreover, is filled with recent mountain slide material and fan deposits which came down from both sides, covering the older moraine and gravel deposits.

Thanks to His Holiness, the high priest of Badrinath, we were allowed to visit, bare-footed, the sacred hot springs. The place is just below the temple and 10—15 meters above the river. The temperature measured 55 centigrades. We estimated the total quantity conducted

[1] The height of the moraine in Sect. 7b, Pl. IV is slightly exaggerated.

into different basins to be 4 liters (about 1 gallon) per second. The water only contains traces of H_2S, but much lime which forms the sinter down to the river[1]. A second but smaller spring comes to the surface 50 meters further south. It may be merely an offshoot. The quantity is only 5 liters per minute and the temperature 27° centigrades.

The Region of Satopanth- and Bhagat Kharak Glaciers

a) Tectonics

(Topogr. map 53N, 1936)

Following the old lateral moraine on the north side of the holy Alaknanda west of Mana, we come north of the ice caves to high walls (Pabeigörh), made chiefly of white massive granite, extremely rich in black crystals of tourmaline (Phot. 51, Pl. XIX). Granite with pegmatitic and aplitic dykes have, to a great extent, replaced the metamorphics. The latter, on the north side of the Alaknanda to the north of the Narayan Parbat, dip 30° to N 20 W. This position prevails along the Satopanth glacier east of the Kunaling, but it turns towards the Badrinath, where the dips are 5—35° to N 20 E. The strike of the metamorphics forms thus an arch over the Satopanth glacier, with its convex side to SSE, turning from SSW to W and WNW. Gentle dips also prevail north of the Bhagat Kharak glacier.

Climbing over the north walls of this glacier, at an altitude of 5500—6100 meters, we reach the first stratified rocks upon the granite. It is a black graphitic biotite schist, of a

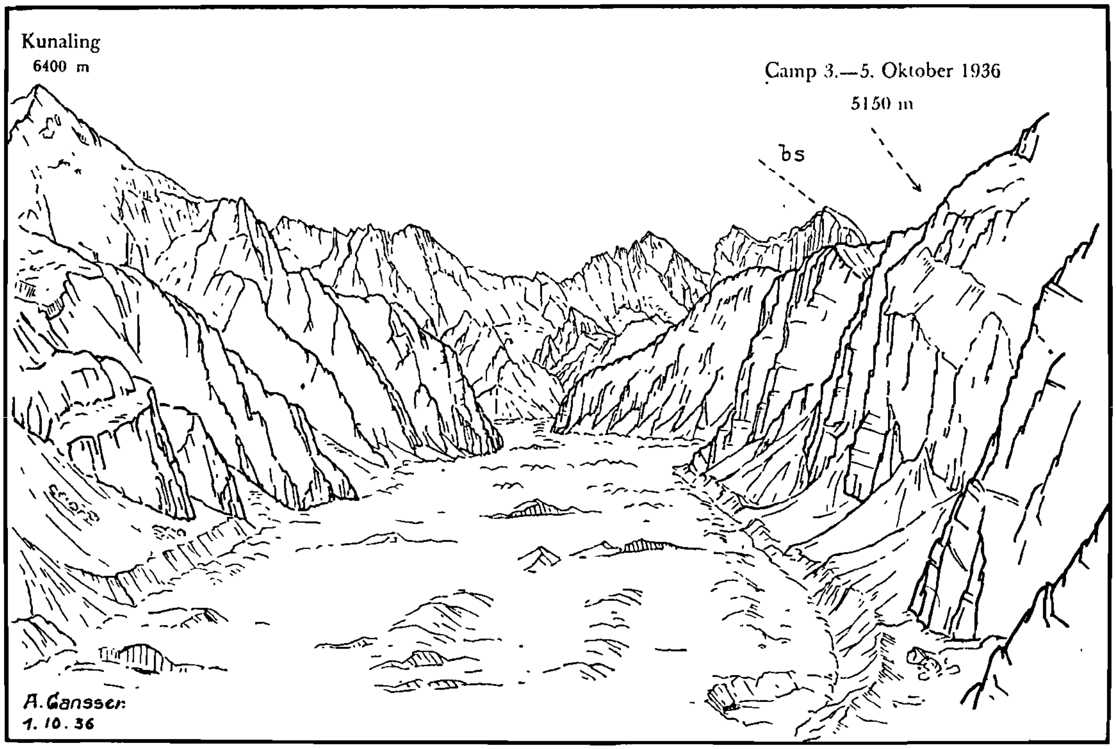


Fig. 58. Bhagat Kharak Glacier, looking to the West.
bs = Basal metamorphic sedimentaries (Biotite schist) upon granite.

[1] When His Holiness asked us, if there were also stones that are growing, we could just show him this sinter as a growing stone.

north-eastern dip of 10—35°, which strongly contrasts with the massive white granite below and above. It is already recognizable from below at a distance of ten miles in the background of Bhagat Kharak glacier, where it forms the top layer of sharp unnamed peaks, 6500 and 7000 meters high (Fig. 58).

Apparently the crest north of Bhagat Kharak marks on the whole the basis of the Algonkian sedimentary series which forms the more gentle mountains north of the Arwa valley.

b) Rivers and Glaciers

The main river coming from the North above Mana is called Saraswati, whereas its western afflux is named Alaknanda. The latter originates at the gate of the Satopanth glacier, the holiest of the Ganges sources.

Just above the afflux, a natural bridge is made by a huge block squeezed in the epigenetic gorge. The former issue, now covered with a great mass of scree material, is apparently due to an eastern mountain fall above the village of Mana, on the east side of the gorge. On September 30th, 1936, after two days without rain, the amount of water of the Alàknanda glacier river was approximated at about $^1/_3$ of that of the Saraswati.

The trail on the north side of the Alaknanda leads over moraine and recent scree material to a large terminal moraine of a stage of recession at an altitude of 3600 meters. It may be historical, of only about 100 years of age. The river has cut a V-shaped gorge across the moraines.

Two great glaciers have their actual end near each-other and nearly on the same level: Bhagat Kharak, coming from the West and having a length of nearly 18 kilometers, ends at about 3750 meters; Satopanth, coming from the South-West and 14 kilometers long, has its gate (source of the Ganges) at about 3800 meters[1] (phot. 54, Pl. XX).

Except at these gates where the dark ice is exposed, both these glaciers are uniformly covered with upper moraine for many kilometers. Further up, the ice gradually appears along cracks and hollows. But only the hanging side glaciers are of pure ice (see the numerous photos in 30).

On the Satopanth glacier, at about 4500 meters, we came accross three joined crater-like little lakes. Close to them is a phantastic ice-caverne of pure bluish and glassy black ice, showing steep stratification.

A little lower down, on the right (- south) side, at 4400 meters, is the sacred Satopanth lake. It forms at riangle of about 300×400 meters, barred by the lateral moraines of the Satopanth glacier and a tributary glacier from the south-east. On October 7th, the water was intensely green and full of vermilion tiny plankton-crustaceae. The lake was then 30—40 meters below the sharp moraine crests. According to its high water mark, the level during the monsoon season may be 6 meters higher than we found it in October.

The Satopanth lake is only one prominent instance of a c h a r a c t e r i s t i c m o r p h o l o g i c a l f e a t u r e of both, Satopanth and Bhagat Kharak glaciers: The sharp lateral moraine crests, sometimes doubled, are 10—25 meters above the glacier ice. There is a deep channel between this moraine crest and the rock wall. This depression is usually much deeper than the ice-surface and sometimes (south side of the upper Satopanth) as much as 50—60 meters below the main moraine crest.

These dead external glacier channels are not simply V-shaped valleys cut out by former side streams. In places there is a flat sandy bottom of 100 and more meters width between the external foot of the moraine and the rock wall (Fig. 59). The flats may partly have been lakes which were filled in with sand. In no place did we find distinct polish or striation on the

[1] See phot. 213 in 30.

rock wall, although during the last pleistocene glaciation the ice must have been about 200 meters higher than now. It may therefore be questioned wether similar conditions already existed at a remote period, which prevented the ice from touching the rock walls directly.

However that may be, not only now, but during the stage when the high lateral moraines were deposited and the ice was 10—25 meters higher, the glacier had no force for lateral expansion. It was "riding" upon its moraine, high above the lateral channels, like a lazy stream which fills up its bed instead of deepening it (Fig. 59).

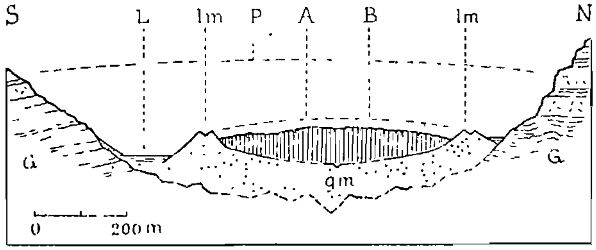


Fig. 59. General Section across a glacier like Satopanth or Bhagat Kharak. (Surface as observed, depth hypothetic.)
G = Gneiss and granite; A = Moraine-covered surface of subrecent glacier; B = dito of the actual glacier; lm = Lateral moraines with sharp crests; gm = Ground moraine; L - Lake or sandy flat.

According to Visser's discoveries[1], in the Karakoram, of glaciers thrust upon each other, we did not fail to pay attention to the way in which two glaciers meet. But the conditions were not so favourable in this part of the Himalaya as we had hoped, for the ice was generally covered with rocks which are not characteristic of the one or other glacier. Moreover our time was too restricted. It seems, however, that:

1. on the upper part of Satopanth a side glacier is thrust upon the main glacier, and this one in turn runs over a side glacier coming towards SE from Badrinath 23420'. A weeker side glacier below Satopanth lake is simply sheared off.
2. on Bhagat Kharak A. GANSSER observed a shear plane of the hanging glacier coming from the NW side of Kunaling 21230' which seems to override the main glacier for more than one kilometer.

There seems to be no rule with regard to main and side glaciers. But we suppose that two items are essential to determine which of the uniting glaciers will have the upper hand: it will be the one that reaches the place of meeting last and the stronger one.

While we were camping at an altitude of 5150 meters on the north side of Bhagat Kharak, from October 2nd to October 5th, we frequently saw ice avalanches falling over the ice-clad walls on the north side of Kunaling, and the thundering seemed to be most frequent at the beginning of the night, probably caused by the expansion of freezing water. The temperature, at 5100 meters, fell over night to 10 centigrades below freezing point. The lower part of that hanging glacier is fed to a large extent by such ice avalanches. It may provide the strength to overrun the main valley glacier (see photo 206 and panorama Pl. IIb in lit. 30).

c) Hoar Ice and Snow Line

The steep and minutely "chiseled" crests and ravines of unclimable slope are well known and characteristic of the high Himalayan peaks of 6000 meters and more. They are also known in the Alps, but not of such a size and extension.

Besides these knife-like cut crests and furrows ("Schneiderillen"), we found in the Badrinath group a second type that we called "Sägerillen", which may be translated as saw-furrows (photo 209 in lit. 30). We could only explain them by attributing them to the effect

[1] Ph. C. VISSER, Gletscherbeobachtungen im Karakorum. Zeitschr. für Gletscherkunde, Bd. XXII 1935.

of direct condensation from high clouds in the form of hoar ice. Indeed, no firn or ice of snow could be formed on such nearly vertical walls (Phot. 55 Pl. XX). Also the crests of these unnamed mountains on the south side of Bhagat Kharak glacier, west of Kunaling, are not of the shape of ordinary ice-flags ("Wächten"), but of rounded "seams" (Säume). The former are growing in the direction of the wind, the latter made of hoar ice, on the contrary, grow against the wind. Both these types of firn- or ice furrows we found only around and above 6000 meters, at Minya Gongkar[1] in Chinese Tibet and in the Himalaya. No expedition has ever been troubled as much with hoar ice as P. BAUER's expedition[2] which had to cut tunnels through the flower-like ice crests of Kangchenjunga as the only way to overcome the hoar-iced crests.

On level ground, on the north side of Bhagat Kharak glacier, we found the snow line in 1936 at an altitude of about 5300 meters, some hundred meters lower than on the Tibetan front, but higher than in the south-eastern Himalaya.

C. The Crystalline Rocks of the Central Thrust Mass

(by A. GANSSER)

1. The Section of the Kali River

The Lower Crystalline Zone (Darchula-Soso)

With a sharp contact, called the Main Central Thrust, the crystalline Rocks at Darchula rest upon the metamorphic limestone series. The usual intermediate zones of quartzite and amphibolites do not reach the gorge, but are seen on the right ridge of the Kali Valley.

The orthogneiss sheet north of Darchula consists in its lower part of large layers of biotite-alkalifeldspar-gneisses with scanty plagioclase. It is a fairly homogeneous orthorock. The orthoclase forms large perthitic and somewhat sericitized grains. The quartz, also in large grains, has a strongly undulatory extinction and shows a typical mortar texture ("Mörtelstruktur"). It also borders in parts sharply on to the fine-grained ground mass which is chiefly composed of quartz and sericite. In it occurs restrictively an acid plagioclase, rarely forming small grains with twin lamellas. The strongly pleochroitic biotite is concentrated in heaps. Here and there also rather large muscovite scales occur. With the biotite some magnetite is associated. Further accessories are apatite and zircon. The large feldspar and quartz produce a porphyroblastic appearance. The structure is lenticular to schisty.

The thick basal gneiss bodies pass upwards to more schisty true augengneisses. They are of the muscovite-biotite-augengneiss type. Compared with the more massive varieties, the alkalifeldspars diminish considerably. The rock shows more signs of tectonical influence. The biotite gets more finely scaly and is associated with muscovite. Curiously enough, the large minerals which also forms the augen are on the whole strongly undulatory quartzes. Macroscopically, the quartz is distinctly violet and, therefore, an amethyst.

Half way up to Khela, similar though more schistose rocks are encountered. Macroscopically, the large rounded grains of amethyst-couloured quartz are striking. The rock is minutely folded. It may be called a biotite-amethyst-sericite schist. According to the mineral contents, it is regarded as an extremely schistose augengneiss. The feldspar is no longer clear and mainly sericitized. The amethyst is of strongly undulatory extinction, and shows distinct "Böhm'sche Streifung" at about 45° to the direction of extinction. The biotite is sericitic and finely scaly. Besides the tectonical influence, the rock too seems primarily to have

[1] ARNOLD HEIM: Minya Gongkar, Forschungsreise ins Hochgebirge v. Chinesisch Tibet. Bern 1933.

[2] B. BAUER: Um den Kantsch. München 1933 (highly impressive photographs).

changed its position. Indeed, it might be regarded as a schistose quartzporphyry — perhaps a marginal facies of the gneisses described above. This interpretation is all the more plausible as we find interbedded para-schists towards Khela, partly accompanied by amphibolitic sills. It is but at the village itself that orthogneisses again occur, belonging to a higher subdivision.

The basic sill south of Khela is a quartzose biotite-amphibolite of 3—5 meters thickness in paragneiss. Large hornblende, somewhat non-homogeneous and of a blue-green pleochroism predominates. Together with it is magnetite in abundance, partly included in the hornblende. The frequent fine scaly brown biotite is intimately bound up with the hornblende and also occurs inside the larger amphiboles. Compared with the abundant quartz, the plagioclase (andesine) is less abundant. To judge from the high content of biotite and quartz, the present sill may be a para-amphibolite.

The blocks of Khela derive from a mountain slide and are orthogneisses. Similar rocks are also found in a place north of this village, on the left slope of the Dhauli-ganga. The macroscopically uniform biotite gneiss is rich in plagioclase (oligoclase-andesine) and only subordinately bears alkalifeldspar. The biotite forms large scales and is intensely brown pleochroitic. The quartz is of but slightly undulatory extinction. In spite of the scanty contents of alkalifeldspar, the rock, at least macroscopically, is of a granitic aspect. Only at an altitude of about 1900 meters, north of the Dhauli, a new zone of paraschists follows. It extends up to the thick body of augengneiss at Phangu (Pl. II, Sect. 4). The rock is mainly a fine-grained biotite-sericite schist with little undulatory quartz, brown pleochroitic biotite and sericite distributed in layers.

North of Phangu, we come to an extremely coarse biotite-alkalifeldspar-augengneiss. The huge mountain slide blocks behind the village are a magnificent display. This orthogneiss is a lenticular body of 300 meters thickness at least which pinches out towards east, but may even increase towards west. Macroscopically, large orthoclase individuals of a bluish-gray colour, up to 15 centimeters in length and 8 centimeters in width, are recognized between the streaks of biotite with clear quartz and plagioclase. This orthoclase is more or less idiomorphic. In places the rock is of nearly directionless stucture, the large feldspars being irregularly embedded. Under the microscope, the orthoclase is only little perthitic and frequently forms very beautiful myrmekitic reactions with the plagioclase which, together with a somewhat more acid unmixing type, is an oligoclase-andesine. The quartz is not undulatory and of the shape of polygonal grains. Muscovite is associated with the brown pleochroitic biotite. The titaniferous magnetite is bordered by titanite. Apatite, magnetite and epidote are further accessories.

Special attention is drawn to the very beautiful myrmekitic reactions with orthoclase. Orthoclase is frequently encountered in the slice, surrounded by quartz and bordered by myrmekitic plagioclase. Similar phenomena also occur on the cracks of the larger orthoclase which include quartz and partly muscovite. Apart from the cracks, towards both sides, the myrmekitic plagioclase has grown like coral branches into the orthoclase (phot. 70, Pl. XXIV).

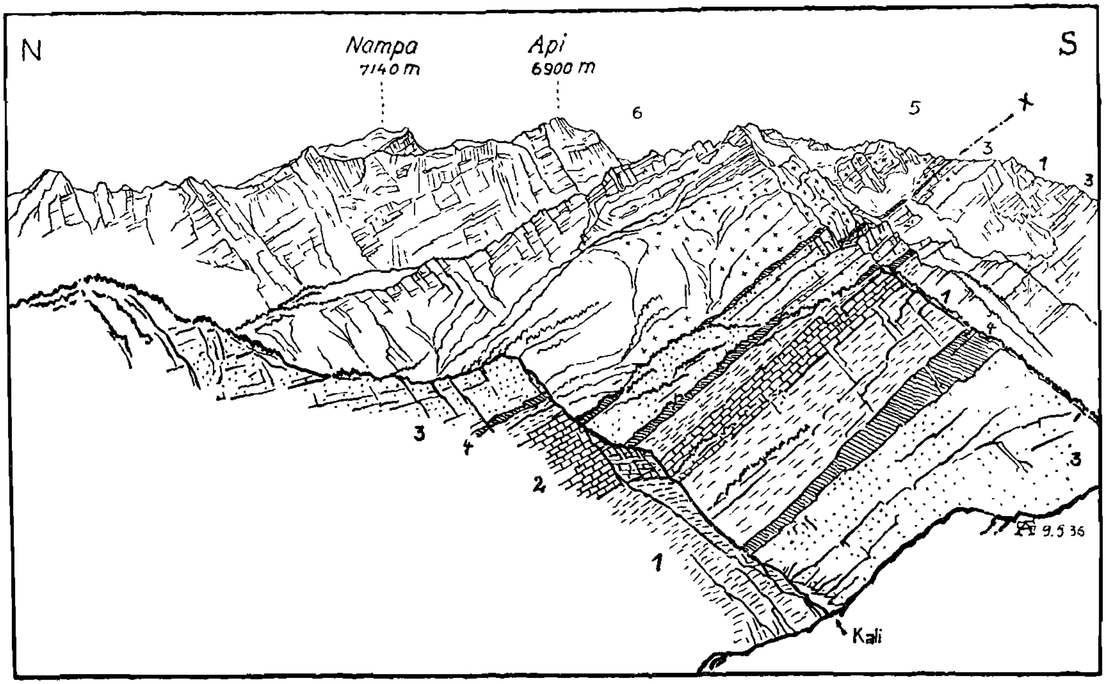
The augengneiss of Phangu is a lenticular body within the biotite-sericite schists. Those overlying the gneiss at Soso are minutely folded, though not irregular on the whole.

The Sedimentary Zone of Sirdang

Above the biotite-sericite schists, at the village of Soso, a new series follows, of white quartzite with amphibolite sills of about 100 meters thickness. Then follow phyllites and the marbles of Sirdang.

The main green massive body at Soso (Fig. 30) is a biotite-amphibolite with macroscopically visible large hornblende in dispersed distribution. Under the microscope, the latter

is distinctly pleochroitic: X = light yellowish-green; Y = olive-green; Z = blue-green. The extinction Z/c is about 17°. The sieve-like inclusions of quartz are remarkable. Andesine is present in large, somewhat lath-shaped, crystals and full of inclusions of hornblende, biotite and epidote. The biotite is abundant in form of small scales. The texture is somewhat ophitic, the structure completely massive. Inspite of the large content of biotite, the present rocks may be ortho-amphibolites of a dioritic origin. The large content of biotite and the occurrence of quartz might on the other hand point to a tonalite as the original rock. But the quartz might also be connected with the main phase of intrusion.



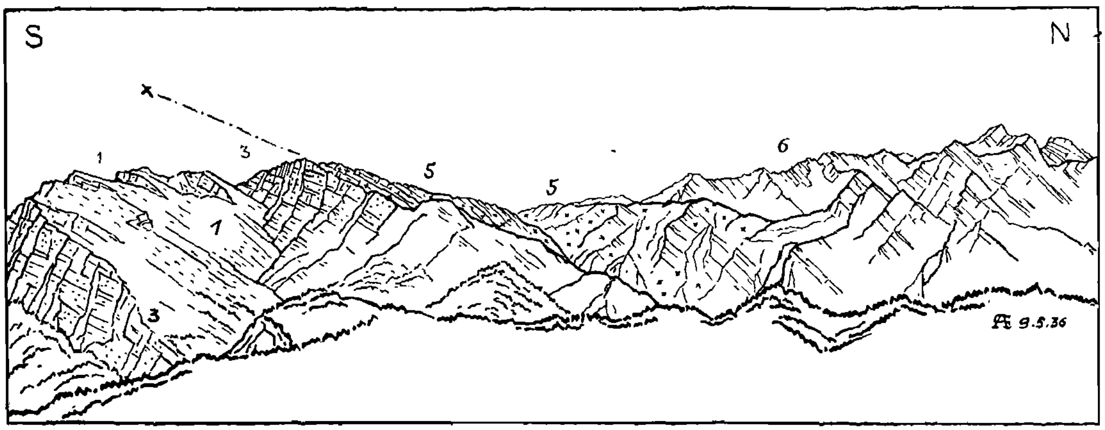


Fig. 60-61. The Zone of Sirdang seen from the height 3100 meters above Soso, Fig. 60 looking towards east; Fig. 61 looking towards west. 1. Biotite phyllite, partly graphitoidic, partly calcareous. 2. White, sericitic marble. 3. Quartzite, more or less sericitic. 4. Dioritic amphibolite. 5. Biotite-muscovite gneiss. 6. Calcsilicate and quartzitic zone. × = Thrust contact of the northern crystalline mass.

Similar types of amphibolite, although more schistose, are again encountered overlying the limestones of Sirdang, and in a similar connection with the quartzite, both towards the limestone and towards the orthogneiss thrust (Section 4b, Pl. II and Fig. 60-61).

At first sight the thick series of slates at Sirdang recall in a striking way the "Bündnerschiefer" or "schistes lustrés" of the Alps. But they are mainly devoid of lime. They are fairly metamorphic, including the small intercalations of micaceous marble.

According to their mineral composition the dark schists of the Zone of Sirdang are graphitoid-sericite-biotite-phyllites. Small scales of biotite together with sericite form minutely folded layers. The graphitoid pigment is spread abundantly over the rock. The quartz forms small polygonal grains. Small idiomorphic tourmaline and rather large zoisite individuals are present as accessories. Inspite of the intercalations of sandy limestone and marbles, the schists are mainly free of carbonate.

The muscovite-bearing calcium-marble, above the village of Sirdang, is about 20 meters thick and of gray tint, caused by irregular distribution of graphitoid. The main mineral is a tabular calcite. Some quartz and muscovite, the scales of which are parallel to the cleavage, are the accessories.

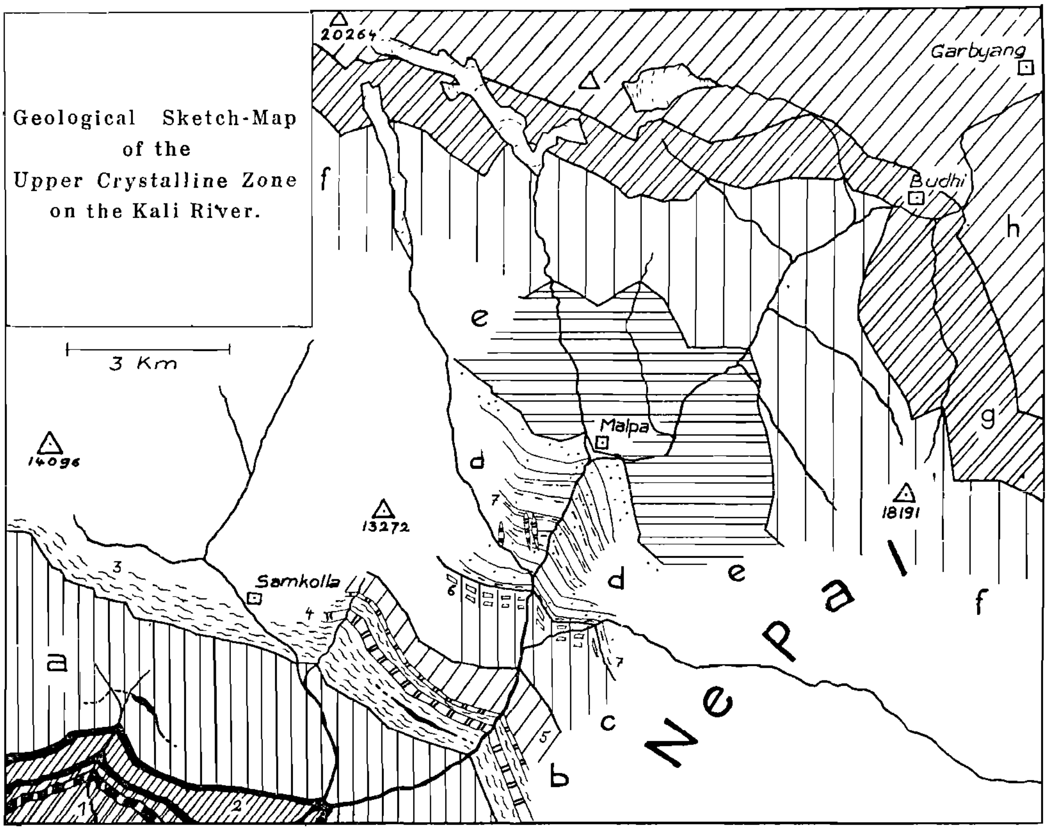


Fig. 62. Sirdang Zone: 1. Graphitoid schists with marbles 2. Quartzite with amphibolite sills. a = Muscovite-biotite gneiss, partly injected, b = Para-schists (3) with orthogneiss (4) and injected gneiss (5); c = Injection gneiss with some calcsilicate layers (6); d = Quartzite with kyanite-garnet schists (7); e = Injection-gneisses with some pegmatite dykes; f = Complex zone of biotite-psammite gneiss with calcsilicate marble layers both pierced by dykes of pegmatite; g = Biotite porphyroblast zone of Bhudi; h = Zone of Garbyang.

Compared with the limestones on the south side of the Main Central Thrust (Darchula), the rocks of Sirdang are much more metamorphic. This results especially from the study of the phyllites and also of the snowwhite sericite-quartzites. The finer-grained main marble, north of Sirdang, of white to pink colour, interwoven with fine layers of sericite and phlogopite, point also to a higher degree of metamorphism.

The Upper Crystalline Zone

Compared with the lower thrust mass, this upper zone is much more complex, although the stratification is remarkably regular. Upwards, towards Garbyang, the metamorphism again decreases as we pass from the Archean to the Cambrian. The regional dip of 30—60° to NE points to a primary succession, although it may be locally repeated by concealed sliding planes. The subdivisions are from below:

a) The basis of the whole series is formed of a large mass of gneiss, mainly consisting of more or less injected muscovite-biotite gneiss.
b) Para-schists pierced by some smaller orthogneiss trains.
c) Injection gneisses with the first limesilicate layers in their upper part.
d) An important zone of quartzite and highly metamorphic mica schists.
e) Injection gneisses overlying the quartzites.
f) Fine-grained biotite-psammite gneisses and calcsilicate layers, the whole profusely pierced by dykes of pegmatite.
g) Towards Budhi, the pegmatites "die out" and the metamorphism decreases.
h) Budhi schists characterized by biotite porphyroblasts.

For the following description compare Pl. II and Fig. 62.

We begin the detailed description in the above order

Zone a

Above the thin amphibolite sills which overlie the sericite quartzites north of Sirdang follows a large series of biotite-muscovite gneiss of irregular banding by injection. These rocks recall somewhat, macroscopically, the Darjeeling gneiss. Rising up to the pass of Samkola, they are well exposed. In the lower part we find a small amphibolite lens. Towards the pass, the injection increases, resulting in the formation of small layers of greisen-like granite.

Under the microscope, the strongly micaceous garnet-bearing biotite-muscovite gneiss shows the following minerals: The lobate quartz is of slightly undulatory extinction. The oligoclase is distinctly twinned. The biotite is highly pleochroitic, dark brown to pale yellow. The muscovite is less abundant, though constantly associated with the biotite. Moreover, there is a relictic, idiomorphic garnet. Apatite is frequent as an accessory. Enclosed within the micas are small oval grains of high refrigence, the peculiar extinction of which suggests an extremely high axial dispersion. They thus seem to be of an apparently lower birefrigence, although the other optical characters point to titanite. The rock is granolepidoblastic, the structure distinctly schistose.

By intense injection the above mentioned rocks become more massive and less micaceous. Such types occur especially on both sides of the Samkola pass, and are determined as tourmaline-bearing biotite-muscovite-alkalifeldspar gneiss. Beside the oligoclase (An = 22), the alkalifeldspars are abundant. With the perthitic orthoclase (2 V = 70°) we find alkalifeldspars of a small negative axial angle (about 50°). Strongly magnified, very fine kryptoperthitic lamellas are visible. They usually also show a marginal, somewhat obliterated microcline-like crosshatched texture. A tricline habitus results in measuring the cleavage with

the universal stage. Even the small angle of the optical axis points to similar feldspars (anorthoclase).

The frequent tourmaline is bluish-gray under the microscope. It is usually confined to aplitic injected layers. Garnet is absent. However, the rock clearly derives from the above mentioned garnetiferous muscovite-biotite gneiss.

Where the injection increased, the rocks get poorer in mica. Apart from that, they still resemble the above mentioned type with which they are connected by a passage. Gradually, massive lenses, excessively rich in quartz, are formed with brilliant and partly somewhat rounded muscovite.

The rock at the summit of the pass is strikingly like a certain greisen. It could be called an extremely quartzose nearly massive muscovite-gneiss. Only the somewhat parallel position of the micas recalls the schistosity. The main constituents are quartz in interlocked grains, and muscovite in large well defined scales. An acid plagioclase with indistinct twin lamellas is only very subordinate. Alkalifeldspars are absent.

On the north side of the pass, south of Samkola, several thin, aplitic layers are found with beautiful radiative tourmaline. The idiomorphic tourmaline is also present in the micaceous layers of the muscovite-biotite gneiss.

Zone b

The passage from zone *a* is covered, at Samkola, by a large mountain slide. Above the injection gneiss we come to dark garnetiferous biotite-psammite-gneiss. This type is repeated many times further up in the Kali gorge, especially in the zone f, together with calcsilicates. Beside abundant quartz, oligoclase-andesine is present. The schistosity is caused by the small scales of biotite. The garnet forms xenomorphic grains. Apatite is an accessory.

Interbedded with the above rock are layers of varied thickness of brilliant staurolite-garnet-biotite-phyllite. Macroscopically, the idiomorphic garnets of a dark red-brown colour are remarkable. They weather out of the schisty layers, each of which may be over 100 meters thick. The larger garnets reach one centimeter in diameter. The staurolite, although smaller, is at once recognized by its red-brown stalks. The following minerals are found under the microscope: quartz predominant in large, undulously extinguishing grains; biotite in small scales together with sericite; the staurolite is somewhat idiomorphic with distinct yellow pleochroism. Of special interest are the garnets, apparently of two different forms: Some are small, idiomorphic crystals without inclusions, others are large, full of inclusions in the core. The inclusions are mainly fine quartz grains with less abundant drop-like magnetite. More towards the edge there is a zone of larger quartz inclusions which marks off the zone of inclusions from the clean marginal zone. Only some single grains of magnetite remain, and quartz is non-existent (Phot. 80, Pl. XXV).

With the psammite gneisses and the phyllites are interbedded a small sill of amphibolite and several layers of orthogneiss. One of the latter especially (zone *b* Nr. 4) attains a thickness of 100 meters. This rock is a more or less garnetiferous muscovite-biotite-alkalifeldspar-gneiss. Beside oligoclase (andesine) of distinct twin lamellas, the anorthoclase-like alkalifeldspars arrest attention. They are again characterized by their indistinct reticulation and the small angle of the optical axis. They predominate amongst the alkalifeldspars. The biotite is intensely brown pleochroitic and goes together with the much larger muscovite grains. Garnet is only present here and there in grains, with few inclusions.

The alkalifeldspar gneisses may develop large augen. They form the ortho-layer in the sedimentary gneisses and schists of zone *b*. In the upper part of zone *b*, alkalifeldspars appear

also within the psammite gneisses, first in the shape of augen, then in real streaks of injection. We thus pass on gradually to zone *c*.

Zone c

Its lower part is exclusively formed of injection gneisses. Between the gray psammitic layers are white aplitic bands. Here too the rocks recall in parts the Darjeeling gneiss.

The upper part of zone *c* is characterized by somewhat streaky banded psammite gneisses within which fine trains of limesilicates are found (Nr. 6, *c*).

First of all, zones of fine reddish garnet are recognized in the quartzose aplitic layers. Gradually stalks up to several centimeters of zoisite appear, between which the garnet is concentrated. In the more calcium-bearing zones ordinary calcite too is present.

The garnetiferous aplitic layers are garnet gneisses rich in quartz. The quartz is minutely interlocked as is usual with injected quartz. Andesine shows clear twin lamellas. (Its axial angle is about 90°; Z of the andesine is higher than E of the quartz). Inspite of the aplitic character and the large contents of quartz, the plagioclases are not very acid, a fact which can be explained by the proximity of the calcsilicates. The biotite forms small brownish scales. The xenomorphic garnet is slightly rose-coloured and free from inclusions. The small distinctly idiomorphic grains of titanite are very typical.

With the retreating of the feldspars and the appearance of abundant zoisite we pass on to the garnetiferous quartzitic zoisite gneisses. The zoisite is an α-zoisite, and marginally somewhat ragged. Plagioclase is subordinate. Where it is lacking, we come to the type of calcite-zoisite-garnet-quartzite. Here, the calcite only is xenomorphic. Partly too, it forms a secondary mineral on α-zoisite. Black tourmaline of macroscopic size is mainly confined to the zones with scanty calcite.

Zone d

At the passage of zone *c* to *d*, forming the basis of a mighty quartzite series, is a zone of gneiss which even macroscopically arrests attention by its abundance of kyanite and garnet. It is a kyanite-garnet-biotite gneiss, which macroscopically much resembles similar types of the basal Darjeeling gneiss. The kyanite is in the shape of large stalks. The biotite forms large brown sheets. The plagioclase is an albite-oligoclase with distinct twin lamellas, but it is subordinate as compared with the quartz. The grains of the latter are intergrown. Rather large grains of a brownish-yellow rutile are joined to the biotite and kyanite. The texture of the rock is grano-lepidoblastic, the structure distinctly schisty.

The above described gneiss gradually passes on to sericite-quartzite of great thickness. It is interbedded with thin layers of sericite schists which contain brilliantly blue kyanite crystals, up to 8 centimeters in length. They are specially developed on the bedding planes of the quartzite, even if the sericite layers are only a few millimeters thick. Garnet is abundant and tourmaline not lacking either. Biotite is subordinate. The kyanitic quartzite is repeated several times in different horizons up to Malpa (Nr. 7 of *d*).

In the middle part of zone *d*, the first dykes of pegmatite were encountered. They traverse the thick quartzitic strata (Pl. II).

Zone e

The pegmatite dykes are increasing in number and size. Above the quartzite walls of Malpa again follow injected augengneisses with a rather sharp boundary. The "augen" attain a length of 10 centimeters and may be elongated to form real aplitic layers. Thus the lenticular character disappears and we pass on to that of a psammite gneiss. More and more

frequently we come across dykes of pegmatite, up to several meters each, often rich in tourmaline, but scanty of other minerals. The pegmatites usually form dykes rather than sills, which, when they occur, only follow along the stratification for a short distance, in order to cut across them again. Even to the smallest details, the dykes and veins may be warped independently of the stratification of the psammite gneiss. No distinct contact phenomena are observed on the gneisses. Even the usual enrichment of biotite on the contacts is lacking.

The gneisses are still of the biotite-psammite gneiss type. Only here and there they contain rather large, somewhat sieve-structured tourmaline together with titanite. At the contact with a pegmatite a slight increase of quartz only is noticed, which seems to derive from the pegmatite. The latter is very fine-grained for 2—3 millimeters off the contact and is mainly composed of quartz and acid plagioclase. The plagioclase is somewhat altered. Some millimeters further inward, rather large alkalifeldspar has been formed. It is in this particular case a large, mostly cross-hatched microcline. Beside it are also found large uniform individuals, regarded as orthoclase or non-twinned microcline. Alkalifeldspars of a small axial angle, as they have frequently been described before, seem to be wanting.

The microscopic aspect of a tourmaline-pegmatite poor in mica, is as follows: Microcline is retreating and in its place fine perthitic orthoclase is found. The plagioclase usually shows distinct twin lamellas and seems to be oligoclase, partly somewhat albitic. The macroscopically black, idiomorphic tourmaline is zonar. In the core it shows a dark lavender-blue pleochroism which changes into brownish yellow towards the edge.

Beside the frequent aplite- and pegmatite dykes real granitic dykes also appear. They may increase to large bodies on the Kali and in the back-ground of the Api-glacier. Mineralogically, these rocks are biotite-bearing muscovite granites. The intermediate aplitic tourmaline-bearing types will not be described. They are especially abundant on the Api glacier (see later chapter). The large, slightly perthitic orthoclase often shows myrmekitic reactions with the albite. The muscovite forms rather large sheets. The subordinate biotite is usually somewhat chloritized.

With the appearance of highly metamorphic calcsilicate-marbles within the psammite gneiss, we pass on to zone *f*.

Zone f

This is the most complex and petrographically richest zone of the central crystalline region. As will be shown later, it was again found by the authors in all other more northwestern sections, bearing exactly the same character.

Between the finely stratified biotite-psammite gneisses are interbedded highly metamorphic layers of limesilicate marble which may attain over 20 meters in thickness. Besides this, the whole series, minutely folded, is pierced with swarms of dykes and veins of pegmatite and aplite which traverse the strata in all directions. There are also dykes of granite of more than 20 meters thickness (Fig. 63).

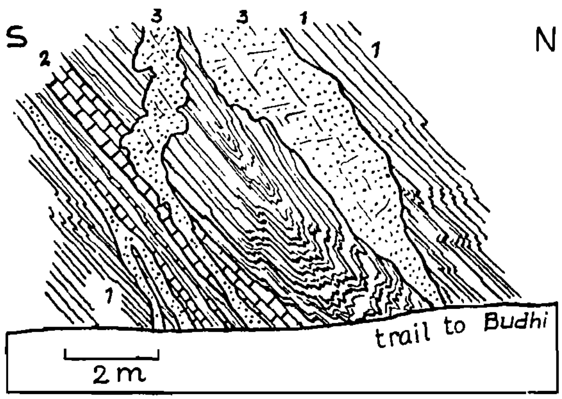


Fig. 63 Detail of zone f.
1 = Fine-grained biotite-psammite gneiss; 2 = Layers of lime-silicate; 3 = pegmatites

The description must be confined to the most important rock types.

Biotite-psammite gneiss forms the basis of all the rocks of zone *f*. They

may contain anorthoclase-like alkalifeldspars. Macroscopically the banded gneisses 'permit to recognize biotite porphyroblasts, stretched in the direction of the schistosity. (In the next series of Budhi, they are of primary importance and even more characteristic.) Beside the abundant quartz and the large scales of biotite, a microcline-like alkalifeldspar is striking. The reticulation is indistinct, and the angle of the optical axis is small, so that it must be counted to the category of anorthoclase-like alkalifeldspars. Some orthoclase and microcline also occur. As a plagioclase we find albite-oligoclase or a somewhat more basic one. A grayish-green pleochroitic tourmaline is associated with the biotite. Apatite is an important accessory.

Within these biotite gneisses are layers of limesilicate, which in the lower part are fine and only a few centimeters thick, but may grow further up to about 20 meters in the shape of marble. The fine layers are frequently repeated within the gneiss. In this case the borders are usually indistinct. Thus we find within the biotite gneisses zones of little biotite, enriched with limesilicates. Such a stratified biotite-limesilicate gneiss peculiarly shows no plagioclase, but much quartz and microcline with clear twin lamellas, and again those microcline-like alkalifeldspars with a distinct crosshatched microcline. The negative angle of the optical axis in the present case is 50—60°. Moreover there are large uniform individuals of alkalifeldspar which must be regarded as orthoclase. Within these layers rich in alkalifeldspar, we find greenish actinolite, diopside and α-zoisite. Frequently there is also an idiomorphic titanite and a roundish epidote. The tiny scales of biotite are partly chloritized.

As soon as the limesilicate layers become larger, they not only form bands in the gneiss, but are banded themselves, so that even macroscopically more epidotic, diopsidic, biotitic and actinolitic layers are recognized. Quartz and plagioclase are still frequent, so that the rock may be defined as a banded limesilicate gneiss. Epidote is found everywhere, although concentrated in layers. Its core is usually less ferruginous. Together with epidote, or by itself, there is a diopsidic augite of faintly green colour. A green pleochroitic actinolitic hornblende is also associated with epidote. The zone rich in hornblende usually bears plagioclase in the form of a basic andesine with distinct twin-lamellas. It is partly zonar, with a more basic edge. The quartz is more restricted to the diopside layers. It forms coarse-grained layers between the hornblende The partly chloritized biotite goes together with the hornblende. Large roundish titanite grains occur too.

The actinolitic layers may locally swell up within the biotite gneiss. Such lenticular bodies are mainly formed of quartz and large fibrous actinolite. Within the actinolitic parts large diopside is found beside the quartz with some calcite. At the contact towards the biotite gneiss, we come to a zone rich in andesine with clinozoisite and little biotite. Only then follows the quartz with its actinolite.

Beside the above-named smaller limesilicate layers we find in the middle part of zone *f* layers up to 20 meters of marble with more or less limesilicates. These marbles are always coarsely crystalline. Within them there are mineralogically poorer rock-types, the few accessories of which are concentrated in layers. The most frequent type is a phlogopite-calc-marble. Beside the predominant calcite, phlogopite is the main accessory mineral. Its pleochroism varies from brown to almost colourless. The angle of the optical axis is relatively large, namley 16° as measured on isolated scales. Scapolite, quartz and muscovite are further accessories. Towards the contact of the biotite gneiss, the phlogopite seems to become enriched.

The scapolite-bearing calcmarble rich in diopside is a widely distributed type. Here the accessories are regularly distributed in the marble. Beside diopside and green hornblende roundish scapolite grains are found. Quartz, andesine, α-zoisite and phlogopite are further accessories. The granoblastic rock is entirely massive.

The marble layers are frequently crossed by pegmatite and granite dykes. It is a striking fact that there are no distinct contact phenomena. They can only be recognized under the microscope. It must further be emphasized that garnet is non-existent along the pegmatite contacts. It is generally rare in the zone *f*, and was found only in the more basic streaks.

The following microscopic statement is related to two pegmatite contacts:

1. A biotitic tourmaline-pegmatite bordering on to a diopsidic calcmarble. At the contact, the pergmatite is formed of large acid oligoclase individuals which are pierced by large zoisite of partly relictic appearance. The optical character points to α-zoisite. Some single biotite scales, of very large size (5 millimeters), and some quartz are relictic. At the real contact, towards the large calcite grains of the marble, there are large scapolites. They are usually bordered by calcite towards the zoisite-andesine granite. In parts the scapolite may also form lamellar inclusions in the calcite.

Together with the calcite, after the scapolite zone, follows large greenish diopside. This, and roundish grains of scapolite form the accessories of the propre marble.

2. Another pegmatite-contact shows mainly quartz on the edge. Towards the marble, some very large clinozoisite individuals appear, recognized even macroscopically as short, olive-brown stalks. The clinozoisite is joined by a basic plagioclase corresponding approximately to a labrador or is even somewhat more basic. Single scapolite grains are also associated with the labrador. After a rather sharp boundary follows a zone of basic plagioclase, diopside-augite, actinolite, epidote-clinozoisite, scapolite, calcite and some quartz, further some rather large grains of titanite and blue tourmaline.

Usually, these complex contact zones are only 1—2 centimeters wide. Only the fine-grained edges of the pegmatite may be somewhat wider. The coarse-grained structure of the marbles is thus in no direct connection with the pegmatite intrusions.

Towards the roof of zone *f*, the pegmatites and also the thicker marble layers decrease. About 1 km south of Budhi we observed, in addition, between the fine-grained biotite schists and the gneisses, some single bands rich in actinolite, usually with reddish biotite layers in their centre. The biotite layers are generally only 2—3 centimeters thick. Nevertheless, it is worth while studying such a layer under the microscope. The following distinctions could be made, beginning from the actinolite band:

1. Actinolite-like hornblende, almost colourless, and quartz.
2. Quartz increases at the expense of the actinolite. Titanite is enriched.
3. Enrichment of tourmaline.
4. Actinolite is enriched again in small individuals. Tourmaline remains, titanite decreases.
5. Actinolite forms large individuals.
6. Biotite is abundant, the actinolite only rare. Tourmaline is still present. Some titanite again occurs.
7. The biotite forms large scales. An almost colourless chlorite is associated to it.
8. The biotite again forms fine scales.
9. The actinolite is again getting more abundant. Tourmaline decreases.
10. Abundance of actinolite, together with some quartz and large titanite individuals. Biotite and tourmaline are absent.

The above series 1—10 is about 2 centimeters wide.

Usually all layers of zone *f* are somewhat psammitic. Proper kataminerals are no longer present.

Zone g (Budhi)

With the "dying out" of the pegmatites and a lesser metamorphism of the crystalline schists, the passage is made from zone *f* to *g*. The schists with biotite porphyroblasts

are the caracteristic feature of zone *g*, which we call the Budhi-zone. They form the passage from the highly metamorphic, more or less micaceous psammite gneisses to the slightly metamorphic series of Garbyang (zone *h*).

Macroscopically the small, usually somewhat rectangular biotite porphyroblasts are placed across the stratification, and in the transverse section are easily recognizable in the phyllitic ground mass.

Under the microscope the fine groundmass proves to be formed of quartz, sericite and the accessories: epidote, tourmaline and magnetite. In it are the large biotite porphyroblasts with sieve-like quartz inclusions. The pleochroism is pale yellow to dark olive-green. The inclusions of quartz were primarily parallel to the schistosity of the rock. (Syngenetic formation of biotite). At the present time they are oblique or at a right angle to the schistosity. The holes formed by the turning of the mineral have been filled with quartz. Usually, the biotites are only sharp-edged on one side; frequently the form is xenomorphic, of relictic reticulation (Phot. 66, Pl. XXIV).

The origin of these biotite porphyroblasts corresponds more or less to the so-called "Tüpfelschiefer" of a beginning deepseated metamorphism. They are recognized in all corresponding sections of the Central Himalaya studied by the authors (see next chapter).

With a decrease of the biotite we come to the monotonous Garbyang zone *h*.

Zone h

The very fine-grained somewhat yellowish schists frequently show green banding, especially in the lower division. The microscope reveals a very fine-grained mixture of calcite, quartz and albite-oligoclase. Calcite forms about 50% of the rock, as supposed, according to the HCl-reaction. The plagioclase shows but rarely twin-lamellas and frequently resembles the small quartz grains in a striking manner. Chlorite and sericite are present as accessories. The former, in small slightly green scales, may become enriched in layers and causes the colouring of the green bands. Rarer accessories are titanite, magnetite, leucoxene and tourmaline. According to the mineral contents the rock is more or less a chloritic metamorphic carbonate-sandstone. It is typically blasto-psammitic and more or less massive under the microscope.

Some Rocks of Api-Glacier and Nampa (Nepal)

The glaciated walls forming the crest between the Nampa (7140 meters) and the Api are chiefly formed of the petrographic zones *e* and *f*. The acid dykes of zone *f* form rather large plugs nicely visible in the background of the Api glacier (Phot. 6 Pl. VII). A complete assortiment of these rocks is found on the moraine of the Api glacier.

The granitic intrusions chiefly consist of fine-grained muscovite-tourmaline-aplite granite. Macroscopically, the black idiomorphic tourmaline needles are striking: The albite-oligoclase is clearly twinned and somewhat more abundant than the alkalifeldspars, which are slightly perthitic orthoclase and microcline with sharply defined twin-lamellas. The scales of muscovite are so scarce that they may be defined as accessories. The idiomorphic tourmaline is zonar, gray-brown outside and gray-blue inside. The main accessory is a roundish apatite.

The size of the grain may vary, although the mineral composition remains unchanged. In order to compare this granitic rock of the Nampa with those of Badrinath, the following analysis was made by Prof. J. Jakob:

SiO_2	71.90				
Al_2O_3	15.41				
Fe_2O_3	— —				
FeO	0.78		1	2	
MgO	0.16	si	392	450	
CaO	0.75	al	49.5	47	
Na_2O	5.26	fm	5.0	7.5	sodium-granite-aplitic magma
K_2O	3.82	c	4.5	3.5	
TiO_2	0.11	alk	41 0	42	
P_2O_5	0.27	k	0.32	0.2	
H_2O+	0.95	mg	0.27	0.2	
H_2O-	— —				
B_2O_3	0 64				
	100.05				

According to NIGGLI's table of determination, it is a sodium-granite-aplitic magma. The corresponding values are indicated (B_2O_3 derives from the tourmaline).

Of the varied rock-types on the moraine amongst which garnetiferous amphibolites are frequent, the kyanite-bearing specimens are of special interest. They probably also belong to zone *f*, because no quartzites of zone *d* were found.

A biotite-kyanite schist probably derives from the zone of biotite-psammite gneisses. The whitish, not very typical stalks of kyanite attain a length of several centimeters. Under the microscope we recognize mainly biotite, kyanite and quartz. The latter is full of small inclusions of rutile, apatite and biotite. Locally fine scales of a colourless chlorite are concentrated. Between the large kyanites a distinct zone of reaction with the biotite is recognized, in as much as the kyanite here never borders directly on to the biotite (Phot. 68, Pl. XXIV). This reaction-zone is formed of quartz and sericite. It seems that kyanite has been formed out of micas, so that each individual of kyanite gets its halo of quartz. Probably the rock rich in mica has again been altered by thermal metamorphism (main injection), so that kyanite was formed. The kyanite containing less quartz than biotite has thus segregated quartz during its formation. The liberated magnesium led to the formation of chlorite.

Another rock rich in kyanite was macroscopically considered to be a greenish black, almost massive biotite-fels. It is in fact a staurolite-bearing kyanite-biotite fels. This is probably an altered lamprophyric rock. The more or less idiomorphic kyanite stalks are found between the abundant olivebrown biotite. In this case there are no reactions between these two minerals. Staurolite is subordinate as distinctly idiomorphic stalks. Rutile and zircon occur as accessories, both in the biotite, more rarely as inclusions in the kyanite. The zircon shows distinct pleochroitic haloes in the biotite.

Other kyanites are found in quartz veins forming blue stalks up to 20 centimeters in length!

The rocks of the Nampa Valley (Nepal) mainly belong to the Garbyang series. Types from the deeper zones are found on the moraines of the Nampa glaciers Nrs. 1, 2 and 3. Only a few types hitherto not encountered will be described, since nothing is known of their relationship.

A carbonate-actinolite-fels comes from the remotest background of the Nampa glacier Nr. 3. The completely massive rock shows, even macroscopically, a dense entanglement of fine actinolite sheaves. This is confirmed by the microscope. The sheaves are beautifully developed and are embedded in a calcitic groundmass. The actinolitic hornblende is only slightly coloured. Between the single sheaves there is slightly pleochroitic biotite. Beside the rather large calcite of the groundmass, the actinolitic hornblende is sprinkled with small calcite inclusions which are regarded as primary, not as altered primary matter. The composition and appearance point to an altered dolomitic sediment.

Beside such carbonate products of transformation we also find quartzitic layers in which actinolite too has been formed by metamorphism. These rocks were found on the moraine of Nampa glacier Nr. 2, and probably derive from a more southerly and lower zone. The country-rock of this garnet-actinolite-quartzite is a biotite-quartzite. Macroscopically the actinolite is at once recognized by its beautiful sheaves with garnet in the quartzitic groundmass. Under the microscope the actinolite is distinctly green pleochroitic and forms incomparably beautiful sheaves (Phot. 27, Pl. XXIV). The single needles are frequently penetrated by quartz. The single garnets only form relictic reticular grains in the quartzose groundmass. Clinozoisite, titanite and calcite, the latter associated with garnet (partly reticular) are present as accessories.

At the contact with the biotite-quartzite the hornblende simply disappears. Clinozoisite is more abundant and biotite appears together with magnetite.

Only the southernmost crest of the Nampa reaches zones *f* and *g*. It is therefore of special interest to mention the occurrence of several dykes of tourmaline-aplite up to 10 meters thickness, extending over a distance of nearly 500 meters on the north side of the Nampa massive, viz. on the right lower slope of the glaciated Nampa Valley Nr. 2 (Fig. 49).

The country rock is a fine brown biotitic quartzitic schist, which passes into the normal rocks of the Garbyang series. The garnetiferous tourmaline-muscovite-aplite is rich in acid plagioclase. Inspite of the peculiar, often non-homogenous composition, it could be determined as albite-oligoclase. Quartz is intergrown with this plagioclase. The muscovite forms large scales. There is also tourmaline. The roundish garnet is macroscopically visible as reddish points. It is an aplitic rock, such as we so frequently encountered in the Kali gorge.

2. The Sections of the Pindar- and Gori Rivers

For the sake of comparison, we again begin the description from S to N, although only a few typical rocks will be mentioned for coordination with the much better exposures of the Kali.

a) The Section of the Pindar River

Similar conditions to those north of Darchula are found north of Loharkhet, where the orthogneiss of the Main Central Thrust overlies the slightly metamorphic series of limestone and quartzite. The muscovite-biotite ortho-augengneiss, with its feldspar augen up to 5 centimeters in length, corresponds to that north of Darchula. North of the pass, at an altitude of 3000 meters, towards the Pindar Valley, the biotite diminishes and the micaceous gneisses pass into bright streaky sericite gneiss containing plenty of tourmaline. South of Kati, sericite schists and psammite gneiss rich in garnet are found. Only at the village of Kati a new and mighty muscovite-biotite gneiss sets in. Similar to the Kali, the dip averaging 30° to NE or NNE is so strikingly constant, that the series has to be considered as being in a normal position. The sedimentary zone of Sirdang, as in the Gori Ganga, has disappeared. In its place, above the injection gneiss which overlaps the augengneiss of Kati, we encounter the typical metamorphic quartzite series which corresponds to zone *d* of the Kali section (Pl. III, Sect. 6 c). Special kyanite layers were not, however, encountered in the Pindar section, but the garnet-sericite-schist intercalations are the same. At Dwali follow again injected muscovite-biotite-psammite-gneisses, similar to zone *e* of the Kali. At the Dak Bungalow of Phurkia one enters into a psammite-gneiss series rich in limesilicate layers, characterized by abundant dykes of pegmatite. of up to 10 meters thickness each, with exactly the same rock types as in the division of the Kali. The dykes are displayed in unique profusion on the lower Pindar Glacier (Fig. 64).

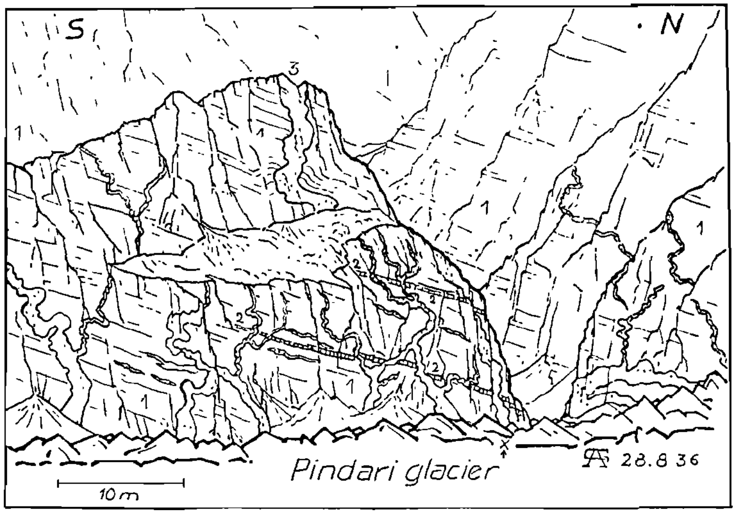


Fig. 64. The Pegmatite Dykes on the right side of the Lower Pindari Glacier.
1. Biotite (-muscovite) psammite gneiss; 2. Limesilicate-marble layers; 3. Pegmatite dykes; x = Arsenopyrite.

Here too, the pegmatites are not rich in minerals. They are tourmaline-muscovite-pegmatites. At x in Fig. 64, some streaky lenses, up to 10 centimeters thickness each, were found in a pegmatite of 3 meters thickness, consisting of finegrained arsenopyrite. This ore is included in quartz and is enriched in the central part of the dyke as a last hydrothermal stage of injection.

More to the north, in the upper region of the Pindari glacier, the pegmatites diminish in number and size, and the psammitic gneisses and schists gradually pass into more or less quartzose sericite schists, in which the garnet is gradually lost, so that only the biotite porphyroblasts remain. The analogy with the Budhi zone *(g)* of the Kali is striking. Even the walls of the further western Pindari glacier consist of garnetiferous biotite porphyroblast schists.

In a groundmass of quartz and sericite large biotite porphyroblasts are embedded, pierced in sieve-like manner by quartz, and also containing some magnetite inclusions. Here too, the porphyroblasts are somewhat turned off from the stratification. The garnet is partly idiomorphic, partly skeleton-like.

Towards north the garnets diminish. The remaining rock is a sericite-biotite porphyroblast schist. The ground mass of quartz and sericite again contains the same somewhat sieve-like biotite porphyroblasts. Besides sericite, chlorite and frequently magnetite occur.

The two rocks described above correspond petrologically completely to the Budhi zone. This is all the more remarkable, as at the upper Pindari glacier (south of the Traill Pass), the overlying slightly metamorphic Martoli series begins — of which the Budhi zone forms the basis. The slightly metamorphic Martoli rocks, on the south side of the Traill Pass, are carbonatic biotite-quartzites. The last biotite occurs in a fine mixture of quartz and calcite with some sericite. It is just recognizable macroscopically, forming tiny dark scales. They are the last remains of the biotite porphyroblasts. Towards the north they disappear, so that the rock resembles a sandy Garbyang limestone.

b) The Section of the Gori Ganga

As a supplement to the tectonical chapter on "The Tranverse Sections of the Jakala Valley and Gori Ganga", some interesting rocks will be briefly described.

The quartzite of Girgaon, below the crystalline Main Central Thrust, contains thin layers of some millimeters of a cobalt-blue scaly mineral. The rock is a kyanite-bearing sericite quartzite. The lobate quartz is not undulatory. Kyanite is present in small single individuals as an accessory. The deeply blue scales are found together with sericite. The refrigence is about equal to that of muscovite. The birefrigence is medium-sized. The isolated mineral which

is no more mica-like, is distinctly pleochroitic, from colourless to sky-blue. The negative angle 2V of the optical axes, measured on isolated scales, is 76—78°. We thank Professor Dr. C. BURRI for the determination as lazulite.

The huge mass of overlying gneiss, upward of Mansiari, is biotite-alkalifeldspar-gneiss (Augengneiss) with layers of muscovite-gneiss which resemble the brilliant greisen-like muscovite rock of the Samkola Pass (Zone *a* of the Kali). The intercalations are quartzose titanitic amphibolites with gray-green pleochroitic hornblende and oligoclase-andesine.

The Augengneiss of Nahar is a biotite-muscovite-alkalifeldspar-gneiss with large augen, corresponding to an intensely injected biotite-gneiss. The orthoclase forms large, slightly perthitic individuals, with partly myrmekitic reactions. Less abundant are microcline which is clearly crosshatched, and an anorthoclase-like alkalifeldspar similar to that of Samkola. Oligoclase-andesine forms fairly large grains. The biotite predominates over the muscovite. The accessories are apatite, chlorite (from biotite), epidote and rutile, the latter in fine needles included in biotite. The quartz which projects sinuously into the feldspars may have been introduced by injection. The present rock may correspond, petrographically, to zone *c* or *e* of the Kali section.

A special quartzite series, like that of the Kali, of the Pindar and the Alakanda, seems not to occur in the Gori Valley. It must, however, be mentioned that the region was traversed during terrible rain and that our study of it needs therefore some improvement.

Above the augengneiss of Tibu follows the zone with the abundant pegmatites and the limesilicates. It certainly corresponds to zone *f* of the Kali and is found in the same position on the Pindar.

At Rilkot begins zone *g* with the typical biotite-porphyroblast schists. They are partly black on account of graphitoid substance. Under the microscope the graphitoid-sericite-biotite-schist once more presents the sieve-like idiomorphic biotite porphyroblasts which are turned at an angle to the stratification. Staurolite, garnet, magnetite, tourmaline and an acid xenomorphic plagioclase with graphitoid inclusions are the accessories. The whole rock is schistose and leads on to the Martoli phyllite.

3. The Section of the Alaknanda up to the Satopanth and Bhagat Kharak Glaciers

a) The Alaknanda Section (Pl. IV, Sect. 7b)

Joshimath is already situated within the zone of biotite-muscovite-injection gneiss which resembles certain types of Darjeeling. It contains some accessory garnet in the psammitic layers, similar to Darjeeling gneiss, and tourmaline. Limesilicates with some garnet and diopside are rarely encountered; they again are similar to the Darjeeling types.

North of Vishnuprayag the injection decreases and quartzitic streaks become separated from the more micaceous ones. The former are impure, gray, and show garnet beside fine scales of muscovite. The mica schist layers with muscovite and biotite of similar importance, are highly garnetiferous.

At the first bridge north of Vishnuprayag we come across a series of about 500 meters of biotite-muscovite schists which are also rich in garnet. The garnet porphyroblasts are frequently bordered by biotite. Some limesilicate streaks appear with garnet and diopside. This zone may correspond to the somewhat quartzitic garnet-mica-schists west of Rini,

in the Dhauli Valley (Garhwal), which also contain limesilicates. The garnet-mica schists with kyanite and some streaks of limesilicate, west of Dhali, belong to a more southerly zone.

North of the garnet-mica schists of Vishnuprayag we come to the huge series of quartzitic rocks to which already J. B. AUDEN (4) drew attention. He photographed the beautiful primary diagonal current-bedding. The quartzites are more or less gneissified. AUDEN calls them granulite. But they are not everywhere of a gneissic character and may be normal quartzites. South of Pandukeshwar, more small intercalations of mica schists are encountered. They are usually found on the bedding planes.

As already noted by AUDEN, the mighty quartzites pass at the bridge north of Painor into rusty weathered parabiotite schists which are partly injected and thus show irregular augen of feldspar and quartz. AUDEN also mentions the rich limesilicate layers which may be followed even beyond Badrinath.

Half a kilometer north of the upper bridge, above Painor, the different limesilicate layers appear within the injected biotite gneisses.

In this place are also found two green layers of about 1 meter each. They are garnet-amphibolites rich in quartz and biotite. The short stalks of hornblende are intensely green. The oligoclase-andesine crystals are sinuous, crowded out by quartz which also forms roundish inclusions. The large roundish garnets are pierced sieve-like by quartz inclusions. The biotite goes together with hornblende and magnetite. Some apatite is included in the hornblende. The striking intergrowth of this amphibolite with quartz is related to the general injection.

In the region described above, the pegmatite dykes are not yet present. They follow further north.

The single layers of limesilicate marble may attain a thickness of 10 meters. About 300 meters above the garnet-amphibolite, intensely injected gneisses become more abundant again. The streaky distributed micas produce the appearance of a migmatite.

One kilometer south of Badrinath, the limesilicate-marbles, interbedded with finely stratified biotite-psammite-gneiss, may attain over 10 meters thickness each. In parts fine layers rich in diopside are formed within the biotite gneisses; they may gradually pass into real limesilicate marbles.

On the south side of the side valley which comes from the Nilkanta, the pegmatite dykes appear. There, the limesilicates of Badrinath within the biotite-psammite gneisses are vertically erected (Pl. IV).

A scapolite-diopside-marble was found at the contact with the biotite gneiss. Macroscopically it is a fine-grained rock. The scapolite usually forms roundish grains. The diopside is slightly green and is associated with the scapolite in the quartzose zones, while the calcite forms its own mineralogically monotonous layers. On the edge of the diopside, an uralitic hornblende is frequently found. Large grains of titanite are irregularly distributed. With the quartzose parts are also associated subordinate albite and some roundish grains of apatite.

The real marbles are light-coloured and show even macroscopically regularly distributed phlogopite and diopside. These diopside-phlogopite-marbles also carry scapolite, quartz, hornblende, acid plagioclase, muscovite and apatite.

The zone of Badrinath, rich in limesilicates, forms a wide anticline and is overlain, at Mana, by injected biotite-muscovite gneiss which is crossed by numerous pegmatite-and aplite dykes.

On the whole, we thus found on the Alaknanda a crystalline series, similar to that of the Pindar and the Kali. The huge quartzites of Pandukeshwar (9 kilometers thickness) correspond to zone *d* of the Kali section (Malpa). The normally overlying injection gneisses of Painor

are equivalent to zone *e*. The typical limesilicates within the biotite-psammite gneisses correspond to zone *f*, although the pegmatites only follow more to the north. Instead of now passing on to the normal sedimentary series of Martoli, we come at Mana once more to the injection gneisses which, by way of their abundant pegmatite dykes, pass on to the tourmaline granites of the Bhagat-Kharak region.

b) The Region of the Satopanth Glacier

Nearly the whole length of the Satopanth glacier is bordered by biotite-psammite gneiss. The tourmaline-granite of the Bhagat-Kharak is here restricted to the higher mountains forming walls of several hundred meters on the north side of Nilkanta, 6600 meters (Phot. 54, Pl. XX).

The biotite gneisses are the continuation of the limesilicate zones of Badrinath and are, here too, frequently interbedded with limesilicate marbles.

The injection of the gneiss is irregular. A rock of granite-like appearance is a sillimanite-garnet-bearing alkalifeldspar gneiss. It might suggest, macroscopically, a highly injected paragneiss (migmatite). Under the microscope the following minerals are recognized: The orthoclase predominates in the shape of undulatory extinguishing individuals. It is slightly perthitic, showing narrow spindles. The albite-oligoclase is distinctly twinned and frequently enclosed in orthoclase. Fine needles of sillimanite are associated with the chestnutbrown biotite. It rarely forms larger individuals with basal cleavage. The garnets are of varied size and somewhat idiomorphic. Here and there tourmaline is found in large idiomorphic stalks. The accessories are apatite, and zircon as an inclusion of biotite with distinct pleochroitic haloes.

Within the fine biotite gneisses, limesilicate zones occur, similar to the Kali section. Locally, instead of the biotite gneisses, we come to fine-grained hornblende gneiss, rich in epidote, which may be regarded as a connecting link to the limesilicates. Usually it forms the adjacent rock to the marbles. Beside an intensely olive-green hornblende, quartz is abundant. The feldspars are mainly andesine. Then follow alkalifeldspars, again of a small axial angle. An indistinct crosshatched epidote is equally distributed like hornblende. The accessories are diopside, calcite, titanite, apatite and magnetite.

The limesilicate gneisses and marbles are very plentiful on the right lateral moraine of the Satopanth glacier. Specimens were collected which show in one piece ten mineralogically different layers. These complex limesilicate gneisses frequently form lenticular bands around the diopside cores. The outer parts of the diopside-hornblende gneiss are rich in quartz, andesine, green hornblende and diopside. The accessories are titanite, phlogopite, apatite and calcite. The more interior layers show the passage of scapolite-diopside gneiss to diopside fels. Here too, we encounter quartz. The plagioclase is non-homogeneous. Marginally, andesine is determined with distinct twin lamellas. The same grain of andesine may pass inwards to non-homogeneous, basic plagioclase of bytownite to anorthite type. No clear zonar growth is present. Diopside is associated with the feldspars and layers of scapolite with hornblende.

Beside these still gneissic limesilicate layers we find the real limesilicate marbles, usually as phlogopite-diopside marble, with more or less hornblende and an accessory basic plagioclase. Pure white marbles also are not lacking. Here and there amphibolitic layers are found in the white marbles.

A specimen of a large block from the right lateral moraine of Satopanth is a tourmaline-bearing phlogopite-amphibolite with scanty feldspar. It is mainly composed of hornblende of slightly bluish-green pleochroism, of phlogopite and large individuals of tourmaline. The basic plagioclase (bytownite) is an accessory, and so are apatite, titanite and pyrite.

c) The Region of Bhagat Kharak Glacier

The layers of white tourmaline granite, which on the Satopanth only form the walls of the summits, come down to the Bhagat Kharak glacier on account of their general dip of 10—20° towards north. They also become much more important. Indeed, a decrease of the granitic intrusion towards south is demonstrated by its disappearance south of the flat anticline of Badrinath. The magnificent mountains of the Badrinath group surrounding the Bhagat Kharak Glacier[1] are chiefly formed of bright granite.

Along the lower northern side of Bhagat Kharak glacier some large zones of injection gneiss are seen. Also, in the main granite zone, homogeneous orthogneisses are enclosed, which are different from the injection gneisses. Apparently these gneisses are older than the massive granite. Aplitic dykes, connected with the granite, are seen crossing the gneiss.

Amongst the gneisses we can distinguish three main types:

1) The most widely distributed one is a biotite-granite gneiss. It is rich in large, very beautiful perthitic to antiperthitic orthoclase. Together with the closely interlocked quartz, it is the main mineral constituent. The albite-oligoclase is somewhat subordinate. It forms beautiful myrmekitic reactions with the orthoclase. Other alkalifeldspars are also subordinate. With their distinct crosshatching they must belong to the category of microcline, though characterized by a small axial angle. The biotite is somewhat bleached. Its inclusions of orthite show pleochroitic haloes. Muscovite is only subordinate. Tourmaline is a further accessory.

2) The next type is a muscovite-granite gneiss. It resembles the former one, but in place of the biotite there is muscovite. Albite-oligoclase is somewhat more abundant, and amongst alkalifeldspars there is also normal microcline. Macroscopically this rock-type is more schistose.

3) The biotite-alkalifeldspar gneiss shows perthitic orthoclase. The large porphyroblasts are recognized even macroscopically. On the edge they are replaced by albite-oligoclase with beautiful myrmekitic reactions. The biotite is lenticularly concentrated as can even macroscopically be seen. Garnet in small xenomorphic grains is pedominant amongst the accessories.

The massive biotite-muscovite-tourmaline granite and granite-aplite are characterized by their abundance of tourmaline. This distinguishes them from the gneisses which carry tourmaline only as an accessory. Although, on the whole, composed rather uniformly, the granites differ in size of the grain and in their contents of mica.

The predominant types are the following:

1) Biotite-muscovite-tourmaline-granite, with large orthoclase of perthitic to antiperthitic unmixture. Microcline-like alkalifeldspars of a small axial angle are subordinate. Albite-oligoclase is less abundant. The quartz is distinctly interlocked and of slightly undulatory extinction. Muscovite usually forms larger scales in which the biotite is enclosed. Rocks with large idiomorphic muscovite scales, up to 2 centimeters, show small idiomorphic biotite inclusions which are concentrated in the centre of the muscovite. The biotite frequently shows pleochroitic haloes. The large grayish-brown to bluish-gray pleochroitic tourmaline is important.

A fine-grained rock is determined as muscovite-biotite-tourmaline-aplite-granite. It bears some garnet which is also found in the ordinary aplite. The fine-grained massive rock is the most frequent tourmaline-granite and corresponds to the types described in connection with the Api glacier in Nepal. The two analyses may be compared:

[1] See the Photo-Panorama Pl. II and the Photos Nr. 203—211 of Lit. 30.

Tourmaline-Aplite-Granite Bhaghat-Kharak-Glacier		(NIGGLI values)		Aplite-Tourmaline Granite Apí Glacier	Aplite granitic Magma
SiO_2	73.38				
Al_2O_3	14.56				
Fe_2O_3	—				
FeO	0.80	si	426	392	460
MgO	0.11	al	50	49.5	47
CaO	0.81	fm	5	5	8
Na_2O	4.27	c	5	4.5	5
K_2O	4.17	alk	40	41	40
TiO_2	0.08	k	0.39	0.32	0.45
P_2O_5	0.19	mg	0.20	0.27	0.25
H_2O+	1.57				
H_2O-	—				
B_2O_3	0.22 (in tourmaline)				
	100.16				

According to NIGGLI's table of determination it is an aplite-granitic magma. The corresponding magma types are indicated in the third column. A comparison of the two analyses shows a good accord, except for slight differences in the al-alk and the k-values.

The real aplites are frequent, usually in the form of muscovite-and garnet-bearing tourmaline-aplite.

Towards north-west the whole granitic mass of the Bhagat Khararak is overlain by black schists. Some lenticular inclusions are also found in the granite which seems to be younger. The schists are determined as quartzitic graphitoid biotite gneiss and quartzitic graphitoid schists. They seem to represent the old sedimentary cover into which the younger granite intruded. From a peak (6100 meters), between the Bhagat Kharak and the Arwa glacier, they could be seen as far as the bordering western crest of the Arwa Valley,

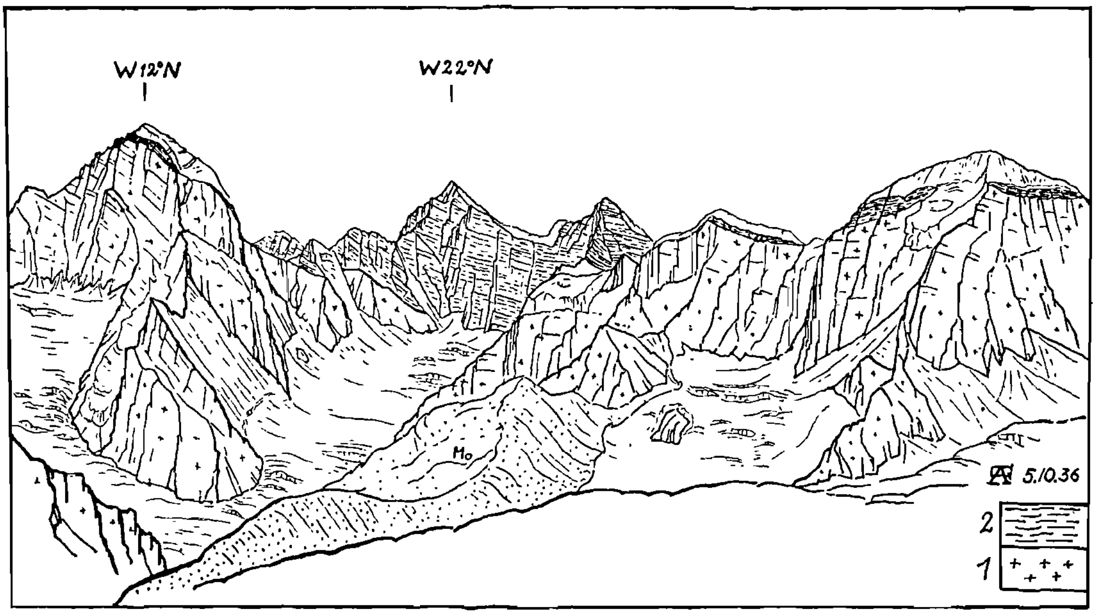


Fig. 65. The North-western Region of Bhagat Kharak, showing the Black Schists covering the Granite.
1. Tourmaline-Granite and Aplite-Granite; 2. Black graphitoid Biotite schists; Mo = Recent moraines. The two peaks (in W 12 N and W 22 N) are about 6500 to 7000 meters high.

partly forming the summits on the watershed to the Gangotri glacier. There the schists are practically horizontal. In the back-ground of Bhagat Kharak, the highest summits are capped by the black schists which sharply overlie the aplitic border zone of the granite (Fig. 65). The Tibetan-like smooth forms of the surface more to the north is caused by these metamorphic sedimentaries which overlie the granite.

Finally, attention may be drawn to a rare pegmatite which was found on the northern slope of the Bhagat Kharak glacier, above its middle part, though only in a loose block. It is a spodumene-pegmatite. Macroscopically the white quartzose rock is formed of more or less idiomorphic colourless stalks, up to 10 centimeters in length. Under the microscope the following minerals were recognized: lath-shaped oligoclase-andesine, orthoclase and large quartz grains. But the chief and striking mineral forms are large and beautiful colourless stalks with polysynthetic twin lamellas. The medium-sized positive angle of the axis, the striking cleavage of the augite-type, as well as the contents of Lithium (see analyses), point to spodumene. The extinction Z/c (also of the twin lamellas) is 27—28°.

The spodumene predominates over all the minerals. This interesting rock is of the following chemical composition (analyst Prof. J. JAKOB):

Spodumene-Pegmatite (Bhagat-Kharak Glacier)

SiO_2	72.95		
Al_2O_3	19.55		
Fe_2O_3	—		
FeO	—		
MgO	—		
MnO—	0.02	si	322
CaO	0.10	al	50.5
Na_2O	2.80	fm	—
K_2O	0.37	c	0.5
Li_2O	4.04	alk	49.0
TiO_2	—		
P_2O_5	—		
H_2O+	0.26		
H_2O-	—		
	100.09		

Attention must also be drawn to an interesting reaction of the spodumene with the orthoclase and partly also with the plagioclase. The long stalks frequently grow into the feldspar in dendritic shape. It seems that the spodumene is replacing the feldspar. Quartz being thereby segregated, the phenomenon seems to resemble the myrmekitic replacing of alkalifeldspar by plagioclase. The border of these myrmekitic spodumene dendrites is finely ramified (Phot. 69, Pl. XXIV).

THE NORTHERN RANGES

TETHYS-HIMALAYA

Introduction

This region between the Central High Range and the Tibetan Front Range or Zaskar Range appears as a great contrast to the former regions, tectonically, stratigraphically and morphologically. It is made of sedimentary formations of Algonkian to Cretaceous age and tectonically characterized by numerous thrust sheets coming from NE, piled upon each other. Morphologically, the region is shaped to a large extent according to its formations, the Silurian quartzites forming rugged crests and peaks, while the black shales have been weathered out to form valleys or gaps. One of them is the Lebong pass which leads from the longitudinal valley of Kuti to that of the Dhauli Ganga.

Having travelled so far in unfossiliferous regions of partly complicated structure, where the relative age of the formations can only be judged by their grade of metamorphism, we now come to highly fossiliferous mountain ranges. The fossils of some horizons are not only abundant, but also well preserved. Our collection which was presented to the Geological Institute of the Federal High School of Technology (Technische Hochschule) of Zurich is worked out by its paleontologist Professor Dr. A. JEANNET, to whom we owe not only the determinations in the following pages, but also working out of a paleontological volume with numerous designs and photographs of the new and rare species from the Ordovician to the Cretaceous. The ammonites are especially numerous and well preserved. In addition, we made and studied a number of microscopic slices showing an abundant life of foraminifera and radiolarians in the Mesozoic formations.

The whole region behind the Central High Range is thus made essentially of marine deposits. The peaks rising above 6000 meters have been squeezed and pushed up out of an old sea. It is the famous Tethys of E. SUESS which extended from the Alps to the Himalaya. J. B. AUDEN therefore called the Northern Ranges the Tethys Himalaya. Not only the paleogeographic conditions recall those of the Alps—the structure too and the surface of the Northern Ranges show striking resemblances. The first geologist who travelled across the Central Himalaya and as far as the Transhimalaya was Captain R. STRACHEY in 1848, who found marine fossils and recognized the Silurian and other marine formations (see p. 7).

Considering the analogy with the Alps, the Geological Survey of India, at the end of last century, engaged three Austro-german geologists, familiar with the study of the Alps and of the Alpine Triassic especially: Prof. C. DIENER, C. L. GRIESBACH and A. VON KRAFFT, who did pioneer work in the interior region of the Himalaya. Most valuable contributions are due also to Sir HENRY HAYDEN (1904) concerning the famous region of Spiti in the NW Himalaya (32° N, 78° W) which have their bearing on the judgement of the formations in our south-eastern region called Malla Johar. GRIESBACH's work was begun in the highly fossiliferous region of Spiti as early as 1879 Including those north-western countries and all that is related to their geology, GRIESBACH gives a list and partly discusses 130 publications. In referring to this list, we shall only have to deal with the three authors mentioned above, and GRIESBACH's Geology of the Central

Himalayas" with numerous plates and 2 geological maps in 1″ = 4 miles which forms a complete memoir of the Geological Survey of India (20, 1891).

As shown on our geological map, the region we shall describe in this book extends from north-western Nepal to the boundary of Garhwal in the NW, and from the Central High Range to the Tibetan Border Range, the latter included. The stratigraphy of this region, in GRIESBACH's memoir, is largely based on the results in Spiti and applied to the south-eastern region in a rather artificial way. On going to the field with his geological map at hand, including the skillfully drawn tracings of sections, we were surprised to find that they were based on much imagination. Thus, instead of a normally folded and faulted region, we found one of thrusting towards SW, with several beautifully visible thrusts upon each other, which, with the exception of one, were overlooked by GRIESBACH.

The Transverse Section of the Upper Kali

On pages 35–41 we described the section of the Kali river along Nepal. We shall now continue towards NE, starting from the region of Garbyang.

a) Tectonics and Stratigraphy (Pl. II, Sect. 4b)

Above the schists of Budhi with their characteristic porphyroblasts of biotite as a last expression of contact metamorphism, we come to the great and normal, although locally crumpled series of Garbyang. It is chiefly formed of slightly sericitic and arenaceous calcareous phyllite, with dolomitic and green chloritic layers. The latter enable us to subdivide the great phyllitic series between Budhi and Gunji. They are problably a product of former basic tuffs, similar to the so-called bentonites of America. The rusty brown weathering of the dolomitic and chloritic layers makes it possible to recognize the Garbyang series at a distance.

The Lower Garbyang subdivision of nearly 2 kilometers thickness gradually passes into a similar series of calcphyllites (Upper Garbyang). Its normal position and regular dip of 40—50°[1] towards north enables us to determine the thickness which is little less than 3 kilometers. The lower half of the Upper Garbyang series is more calcareous, with sandy limestones forming high walls, while the upper half shows a more red brown weathering.

The total thickness of the Garbyang series above its injected basis, between Budhi and Gunji, is thus 4,5 kilometers. Including the Budhi series, the thickness of the sediments older than Silurian is 5,5 kilometers.

GRIESBACH, in his memoir, called the lowest sedimentary system of the Central Himalayas Haimanta which in Sanscrit signifies "snow-covered". His description (20, p. 51), however, largely applies to the north-western regions and is not applicable to the Kali section. Here we have looked in vain for the quartzites and conglomerates, and we cannot confirm his statement (p. 49) that "the Haimantas are invariably separated from the Silurians by a zone of bright red quartz shales, which I have traced from the extreme north-western limit of my area (Spiti) to the frontiers of Nepal". GRIESBACH reduces STRACHEY's estimate of 9000′ thickness of his "azoic slates" to 4000′, whereas at Garbyang we come to an estimate of 15000′ and even much more for the Haimantas in the near North West. One of his errors of which we shall give the data later, was to take the red Silurian of Gunji as the same horizon which, in the Dhauli gorge is stratigraphically about 4 kilometers deeper.

The upper limit of the Garbyang series is passed on the trail east of Gunji. The contact seems to be sharp and stratigraphic. The top layers of the Garbyang series are formed of crumpled greenish marly schists. They are stratigraphically overlain by violet sandy clay shales, dipping 35—40° to NE, apparently slightly steeper than the underlying schists. The latter are

[1] In Section 4b, Pl. II somewhat smaller angles are shown on account of the projection which is not exactly in the strike.

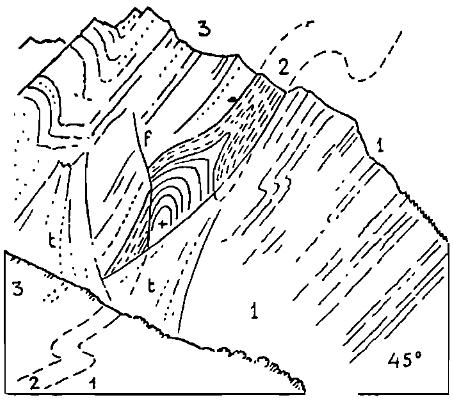


Fig. 66. Cambro-Silurian Contact on the Nepal side of the Kali, seen from Gunji towards ESE. 1 = Garbyang series; 2 = violet shales of basal Silurian; 3 = quartzite series; t = talus. f = fault

of variable thickness for stratigraphical and tectonical reasons. They are intensely folded, squeezed and faulted on the walls of the Nepali side, conformably with the underlying Garbyang shales (Fig. 66).

On the trail the thickness of the violet shale is only 20—30 meters, but the normal thickness at Gunji may be 50 – 100 meters.

No fossils were found except some small white joints of Crinoids in the violet shale.

The immediately overlying strata are not exposed along the trail. On the whole the violet shale is overlain by a thick body of folded quartzite of brown weathering. The upper part, about 400 meters, is regularly bedded and partly made up of dolomite and dolomitic limestone. The dip at the foot of the walls is nearly vertical and the strike accurately W 30 – 35° N.

This brown series is normally overlain by a massive white quartzite of about 150 meters. Then we come to the crumpled syncline with its disharmonic interior folding, photographed and well reproduced by GRIESBACH (20, Pl. 24), though not indicated on his section Pl. 9, Fig. 4. This syncline is made of rusty brown weathered quartz-

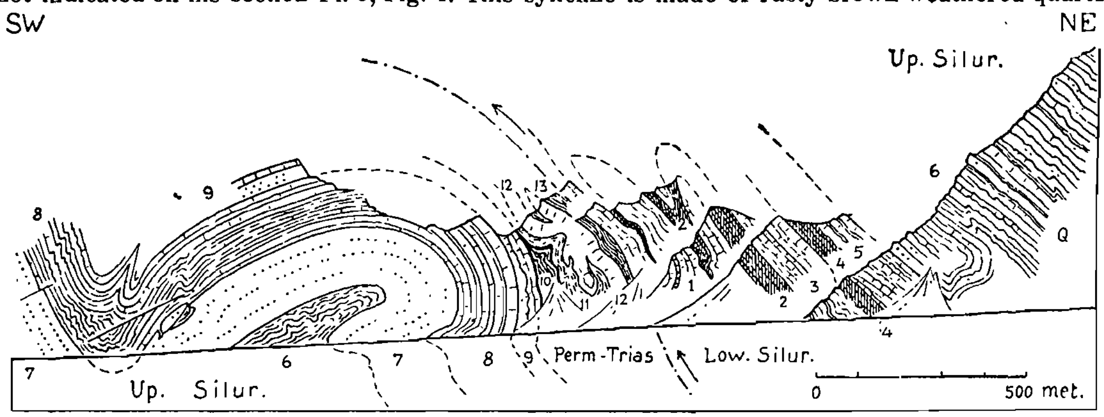


Fig. 67. Details of the Thrust Zone of the Upper Kali below Kalapani.

Lower Silurian	1 = Gray limestone, wavy, about 50 meters, with a bed of echinoderm breccia and 3 meters of quartzite at the base.
	2 = Variegated slaty marls (violet, red and greenish), with small stem-ossicles of Crinoids, 50 —70 meters.
	3 = Calcareous sandstone and sandy limestone with badly preserved smooth Bivalves.
	4 = Variegated marly shale overlain by a bed of 0—6 meters of white massive limestone.
	5 = Well-bedded fine-grained limestone, gray to reddish and greenish, with, cleavage, about 100 meters.
Muth series, Upper Silurian to Devonian	6 = Well-bedded quartzite, with dolomite and limestone beds of brown weathering, about 700 meters. Q = white quartzite band about 20 meters.
	7 = Massive white quartzite, about 150 meters. Sharp limit to
	8 = Well-bedded dolomite-quartzite of rusty weathering, about 150 meters.
	9 = White quartzite and dolomite-quartzite of variable thickness 10— 50 meters.
Perm.	10 = Productus shale, black.
Triassic	11 = Chocolate series, Eotriassic.
	12 = Spotted limestone (Kalapani limestone).
	13 = Kuti shales below talus.

ites and dolomites in repetition of about 150 meters thickness. They seem to be crowned by a last body of white quartzite of irregular thickness (Fig. 67).

We now come to the most interesting and the most complicated tectonical zone, which was completely misunderstood by GRIESBACH. Hard climbing would be necessary for further improvement of the present description.

First we see the thick white Muth-quartzite, forming an anticline overlying towards NE! It is, so far, the only back-folding ("Rückfaltung") found in the Central Himalaya, whereas similar cases are frequent in the Alps. However the reversed limb is only overhanging for 100—150 meters.

Both, this anticline and the syncline on its SW side show a gentle though distinct axial pitch towards NW.

The back-turned front of the white quartzite is regularly overlain by a thick body of brown, well-bedded dolomite. Then follows again a white quartzite covered by dolomitic layers. They are partly reduced and intensely compressed.

Having now traversed the Muth series, we come to a normal, although squeezed and folded series, beginning with black Permian shale and the Triassic sequence: chocolate shale, spotted Middle-Triassic limestone and probably some Kuti shales (Upper Triassic). They are thrust-covered by a Lower Silurian or Ordovician series, with variegated shales and limestones, in the shape of narrow folds.

The thrust-plane is nicely visible on the southeastern side of the valley as a steeply north-easterly inclined shearing plane. In order to work out all the interesting details, a photogrammetric map of 1:10 000 and photographs on a large scale should be taken in the direction of the strike, from high standpoints on both sides of the valley.

The variegated squeezed and folded Silurian seems to be normally overlain by quartzite with limestone and dolomite of great thickness. Certainly this brown series corresponds to what we have regarded as Muth (Upper Silurian to Devonian) in the series underlying the thrust plane.

Before proceeding farther north-eastward, an interesting detail of the series 4 of Fig. 67 is noticed (Fig. 68).

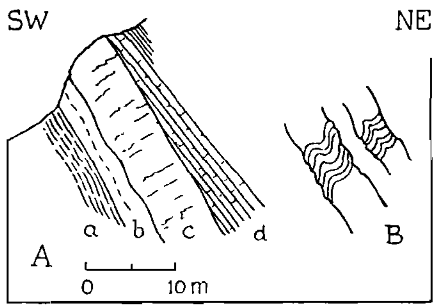


Fig. 68. Detail of the Top of Series 4 in Fig. 67.
A: a = Red shales; b = Red and green marl with sharp contact to c = 0—6 meters of massive fine-grained white limestone. Slight unconformity to d = Well-bedded yellowish marls. B: Folded cleavage in marly Silurian of the same formation.

The sharp contacts of the limestone bed and the slight unconformity of about 5 degrees is of more lithological than stratigraphical interest. These contacts have nothing to do with transgression and must have been formed at the bottom of the deep sea, possibly in short phases of interruption of the sedimentation.

The top of the brown quartzitic to dolomitic series is again formed by a massive white quartzite (Muth quartzite). It rises to the top of the admirable needle point 17634′ of the old map 1″ = 1 mile, and is sharply overlain by black Permian shale and the normal Triassic sequence, the whole being intensely folded.

We are now at the uninhabited stone huts of Kalapani, at about 3700 meters altitude, and look up to both sides of the valley. They are complicated by faults and differ in detail.

The south-eastern side is shown in Fig 69.

If we cross the bridge over the Panka glacier river, we come to a normally NNE dipping series of Lower Triassic and Permian, which is cut off by a striking fault. Between this and

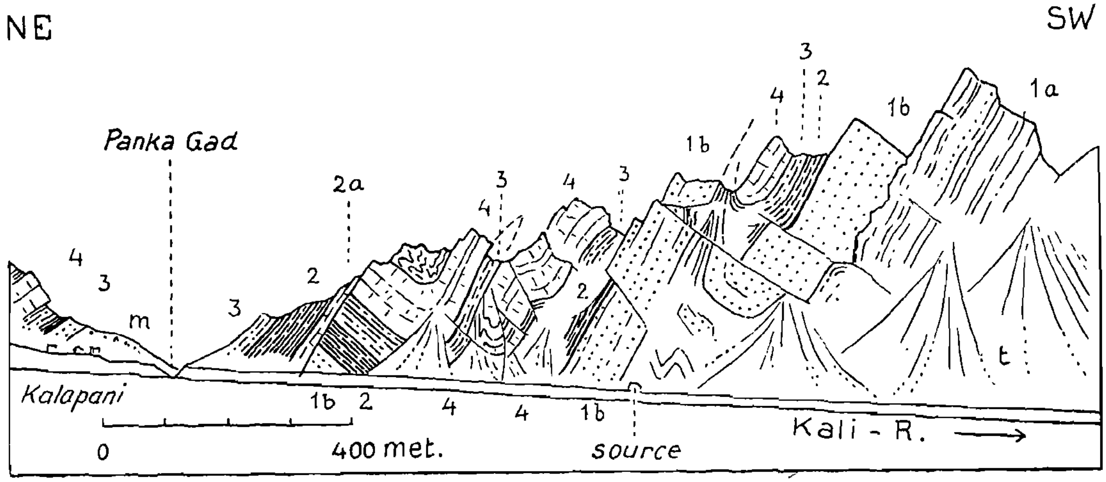


Fig. 69. The Structure of Kalapani on the SE side of the Kali River.

Muth series	1a = Brown dolomitic quartzites
	1b = White quartzite
Permian	2 = Productus shale
Triassic	3 = Chocolate series
	4 = Kalapani limestone

the Silurian quartzite is an intensely folded, crumpled and faulted packing of Triassic sediments (Fig. 69).

A normal section of the Triassic limestone was found on the right (north-eastern) side of Panka Gad above Kalapani. There the stratification is so regular and well exposed that we propose to call it the Kalapani limestone.

This Kalapani limestone thus has a normal thickness of about 55 meters and corresponds mainly to the European Muschelkalk or Middle Triassic, as already known to C. DIENER. The hematitic layer in the middle is rich in large involute ammonites which stick out on the inaccessible wall, where only one good specimen of *Ptychites* cf. *rugifer* could be extracted. This is an Anisian species, while the upper part may represent the Ladinic and? Carnic stage.

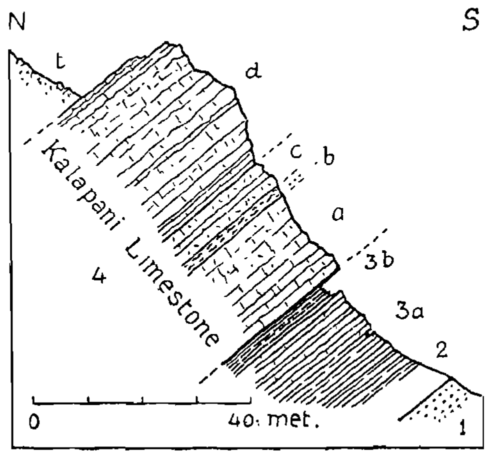


Fig. 70. The Kalapani limestone of Panka Gad, 1 km SE of Kalapani.

1 = Muth quartzite
2 = Covered by talus, probably reduced Productus shale = Kuling shale.
3 = Chocolate series
  a) 18 meters of clay-iron stone layers of 1—2 decimeters with argillaceous shales passing into
  b) a 3 meter band of dark shale. Sharp boundary (conformous discontinuity) to
4 = a) 17 meters of compact gray limestone, of light brown weathering, upper part coarse-grained with shell fragments.
  b) 2 meters limestone spotted with red hematite and large involute ammonites, amongst which *Ptychites* cf. *rugifer* OPP. and *Paraceratites himalayanus* BLANK.
  c) 6 meters of fine grained limestone.
  d) 30 meters well-bedded dense, dark blue limestone, spotted with orange coloured streaks of ankerite. Upper part nodular and thin-bedded, with numerous ammonites of which could be extracted: *Tropites subbulatus* v. HAUER.
t = talus, on Kuti shale.

Unfortunately the contact to the overlying Kuti shales is covered, whereas the lower Triassic and Permian are nicely exposed along the trail immediately south of Kalapani (Fig. 69):

2 a) 10 meters (?) of reddish brown weathered platy limestone (plattiger Kalkstein), with undeterminable fossils, probably a lower and rare Permian horizon, cut off by a fault.
b) 40—50 meters of black Productus shale with ochre concretions and numerous *Productus* of bad preservation in the lower part.

3 a) 1,2 meters brown sandy calcareous layer with cleavage, full of ammonites in very bad preservation.
b) 2 meters black shale.
c) 10 ? meters chocolate shale.

The time at our disposal was too short to search on the other side of the valley the contact of the Kalapani limestone with the "Daonella shales" (Kuti shales).

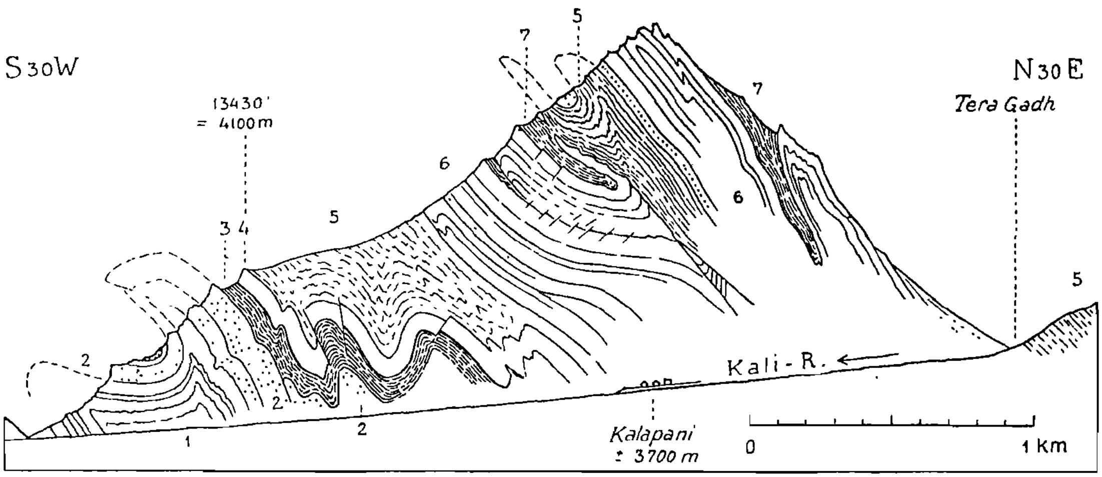


Fig. 71. Sketch of the Structure at Kalapani on the NW side of the Kali.

1 — Dolomite quartzite (Silurian); 2 = Muth quartzite; 3 = Productus- and chocolate shale; 4 = Kalapani limestone (Muschelkalk); 5 = Kuti shale; 6 = Upper Triassic limestone (with quartzite in the lower part?); 7 = ? Spiti shale.

We now follow the Kali further up (Pl. II, Sect. 4 b and Fig. 71). Point 13430' corresponds tectonically to the outcrop of Fig. 70. The folds of Kalapani limestone on the NW side are overlain by dark shales which probably correspond to the Daonella shale of GRIESBACH, but are indicated on his section as white Carboniferous quartzite.

The unnamed mountain crest north of Kalapani is entirely made up of Triassic limestones with quartzite and shale, intensely folded, slickensided and pushed over each-other. The structure shown in Fig. 71 is not imaginative, but directly designed after nature. Thrustfaulting is, in these upper Himalayan formations, combined with folding. The direction of compression was always towards SW.

Beautiful folds of Upper Triassic limestone and black shales (Spiti ?) are seen on the mountains in the background of Tera Gad. The trail to Lipu Lek passes over a bridge to the north side of the Kali and turns towards east. For several kilometers it follows moraine and black micaceous shale of the Kuti facies (Upper Triassic), while the great walls above it, of brown and white limestones and quartzites with subordinate shaly layers, belong chiefly to the Silurian again (Fig. 72).

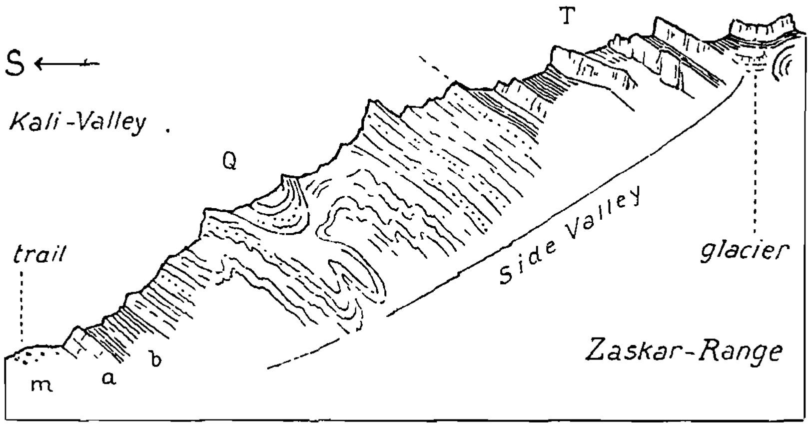


Fig. 72. The Walls of Zaskar Range, North of Lilinthi, above the Trail to Lipu Lek, seen from Lipu Pass.
a = Limestone;
b = Shale of brown weathering;
Q = Quartzilic-dolomitic Silurian;
T = Triassic sequence, repeated.

GRIESBACH (20, p. 192) already recognized that this older part of the Zaskar range is thrust upon the Triassic. The question still remains whether there is a reversed limb along the zone of thrusting. With more time at our disposal and in better weather it would be fascinating to study and to map this region, of which we can only give an approximate idea.

The folded Silurian of the above figure strikes normally ESE and forms the mountain crest east of Lilinthi, from point 16292′ to 17882′ of the old topographic sheet Nr. 62,1″ = 1 mile. The axis of the main fold distinctly rises towards ESE, at an angle of about 15°, so that the red and violet Crinoid shales with yellow limestone intercalations appear east of point 16292′ in remarkable extension. The quartzitic sandstone at the base may even belong to the Ordovician (Fig. 73).

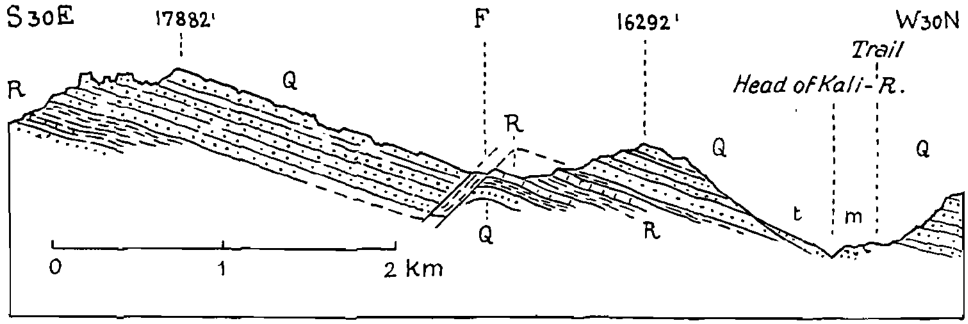


Fig. 73. Longitudinal Diagrammatic Section of the Anticline on the SW side of Lipu Lek, showing axial Pitch and Flexure (F).
Q = Low. Silurian or Ordovician quartzite; R = Red and violet shales and yellowish limestones (Lower Silurian); Q = Brown Muth quartzite; m = Moraine; t = Talus.

About a kilometer east of point 16292′, this red Silurian series is cut off by an important transverse flexure. The south-eastern part of the anticline seems to have slipped about 500 meters down along two parallel planes of south-eastern dip. Thence the anticlinal axis again rises at an angle of 15—20°, with the effect that the red Silurian reappears about 3 km farther ESE, on the SE side of the Tibetan frontier and water shed of the Lipu Lek. At the same place the anticline begins to lean over to the SW (Fig. 74).

The section of Lipu Lek, the most frequented pass to Tibet, 5150′meters, has already been described and designed by GRIESBACH, but in a mistaken way. Indeed, the pass is not on an

anticline, nor on coral limestone, but on regularly isoclinal Silurian quartzites, dipping 35° to NNW. The abnormal strike is caused by the general axial pitch to WNW. GRIESBACH regarded the dark Encrinites limestone in which he found *Trilobites* as Devonian, and in this he may be right.

Lipu Lek is on the normal limb of an anticline with an intensely crumpled Silurian interior, thrust upon upper Triassic shales and limestones. The latter correspond to the Kioto limestone of Spiti. The oolites are characteristic of its lower part. We are here at the eastern continuation of the great thrustfold already recognized by GRIESBACH NE of Kalapani.

On the northern side of Lipu Lek follows a very gentle syncline of fossiliferous Productus shale, also pitching towards WNW. Indeed, the dip of its southern limb is 35° to N 10 W, whereas the northern limb dips 35° to W 30 S. The pitch of the synclinal axis is thus 25° to W 25 N. In the N-S section (Fig. 74) the dip is figured correspondingly less.

The rugged Tibetan boundary crest again forms an anticline, but I could not determine its local structure, whether it was caused by faulting or stratigraphic irregularity (pinching out of Productus shale?)

In the basal part of the synclinal Productus shale we collected the following species (determination by Prof. A. JEANNET):

Productus himalayensis	DIENER
„ *subreticulatus*	MARTIN
„ *Abichi*	WAAGEN
Spirifer tibetanus	DIENER

About 5 km in a direction E 10 S from Lipu Lek, the structure of Fig. 75 is seen, designed at a distance.

This symmetrical anticlinal core may be the south-eastern prolongation of the anticline which forms the Tibetan watershed north of Lipu Lek. If so, it would show a further axial rising and accentuation towards SE.

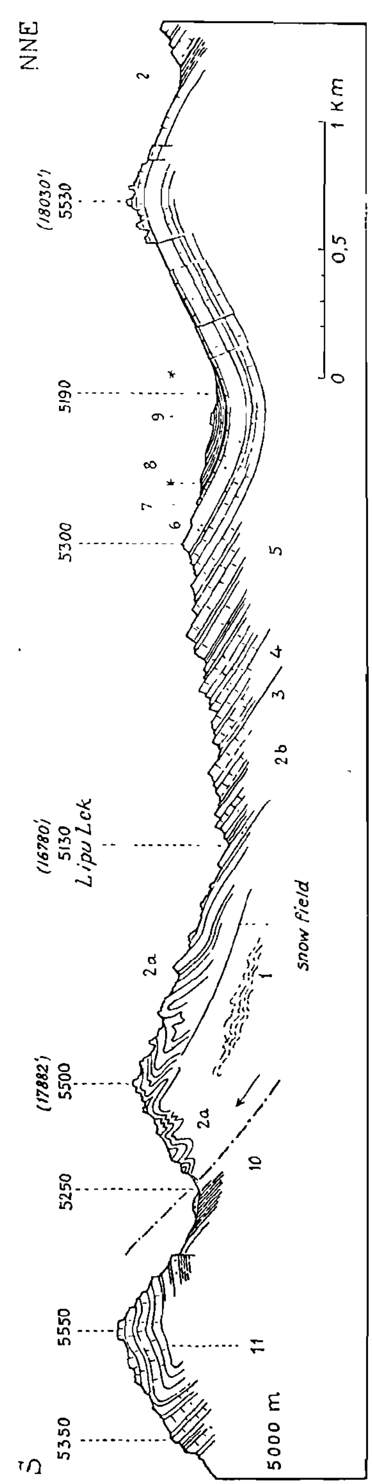


Fig. 74. The Profile of Lipu Lek. 1) Red and violet calcareous Silurian (Crinoid shale); 2) Muth series: a) Brown quartzite of several hundred meters; b) About 100 meters of brown impure quartzite with 3 white quartzite layers of 5—12 meters each, and 10 meters of massive dolomite below the top quartzite; 3) 70—80 meters of dark Crinoid limestone with numerous Crinoid ossicles, resting on 3—5 meters of blue marls; dip 40° to N 10 W; passage to 4) Gray limestone and shales; 5) About 400 meters of well-bedded dense limestone with white spots (corals?), *dipping* 35° to N 10 W; 6) About 60 meters of white quartzite (Muth); sharp boundary to 7) 2—4 meters of limestone; sharp boundary to 8) Black Productus shale with nodular layers and rusty concretions of clay-iron stone, also flint balls of the size of a wallnut. Lower 3 meters rich in Brachiopods, especially a ferruginous lumachelle of 10 centimeters. In the upper part 5 meters of ankeritic limestone (= basal Trias?). Total thickness about 30—40 meters; 9) Nodular ankericitic limestone, 5 meters (Eotriassic), forming gentle syncline; 10) Black upper Triassic shale (Kuti shale?), with cleavage, 50 meters exposed; 11) Well-bedded, partly oolitic gray *Kioto limestone*, Rhaetic.

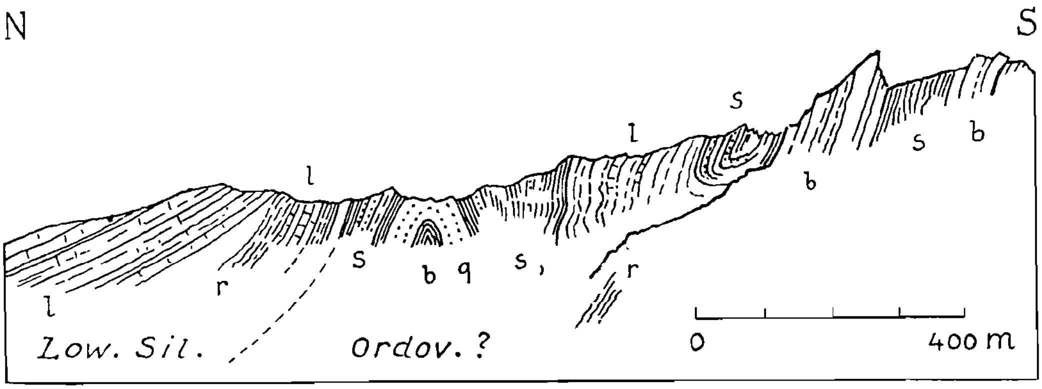


Fig. 75. Section east of Lipu Lek, Tibet (scale approximate).
q = Quartzite; S = Black slates with quartzitic layers; r = Red shales with l = yellowish to brown limestone of lower Silurian; b = Rusty brown strata, probably Silurian dolomite-quartzite.

b) Moraines and Lake Deposits

Starting from Garbyang, we have first to study the remarkable Quaternary deposits on which this important Bhotia village (3140 meters) is situated.

Coming up the Kali river, the great barrier was mentioned which rises 600 meters above Budhi, at the point 10809′ (= 3300 meters) of the topographic map N 62,1″ = 1 mile (see Pl. II, Sect. 4b).

Its upper part, about 50 meters thick, is made of blocks of the Garbyang series and has the aspect of a mountain slide. But we looked out in vain for the niche on the north-western walls where it should have broken off.

Climbing up the escarpment in the gorge from the east side, the material below the cemented block deposit is recognized as a moraine with some scratched pebbles. We therefore suppose that the wall is made by both, moraine and a mountain slide which fell upon it or upon the receding glacier that may have transported the block heap for a short distance (Fig. 76 and Phot. 15, Pl. X).

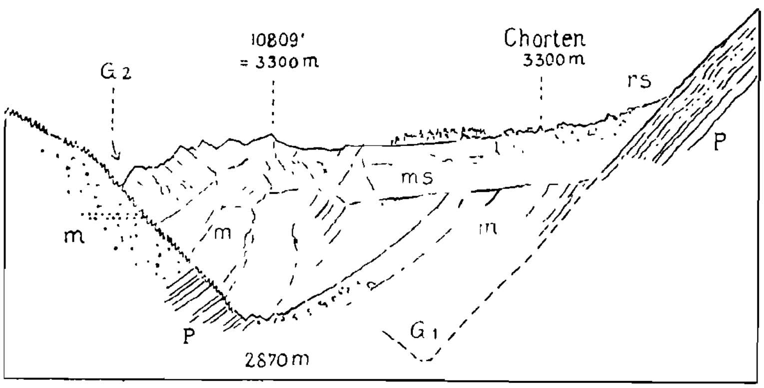


Fig. 76. The Great Barrier of Garbyang, seen from the village towards SW.

P = Phyllite of Garbyang series, m = Moraine; ms = Cemented mountain slide with fluidal stratification on the left; rs = Small recent mountain slide and talus; G1 = Supposed former gorge; G2 = Actual epigenetic gorge.

The former course of the valley was certainly more to the right, and the round-about way cut down into the phyllitic rock is epigenetic. The mouth of the Api side river coming from the SE is made by a waterfall of about 80 meters height.

Obviously, a great Quaternary lake extended behind this dam for at least 7 kilometers, and probably even up to Gunji, which would be 11 kilometers as measured along the course of the river.

The original high level of the lake is preserved in different places. The best is the great circus broken out of the lake deposits at the small village situated 1 kilometer ENE of Gar-

byang, on the SW side of the rocky spur of point 11387'. If the altitude of Garbyang is taken to be 3140 meters, it would be the 3170 meter level, which corresponds to the gravel terrace of the Nepalese village Changru and to that further up the river at Kaua Talla. The next lower terrace is that of the village of Garbyang, 3140 meters.

The main lake deposit is a fine sandy loam of yellowish to olive greenish colour, intercalated with brown bituminous sheets. The top at Garbyang, and a part below the bungalow, is of the type of a varve deposit, with minute stratification which probably corresponds to annual changes of deposition, similar to the famous glacial varves of Sweden and New York. However, it is impossible to count the total number of varves on account of the slipping of the slope and the interruptions of the outcrops by gravel and moraine.

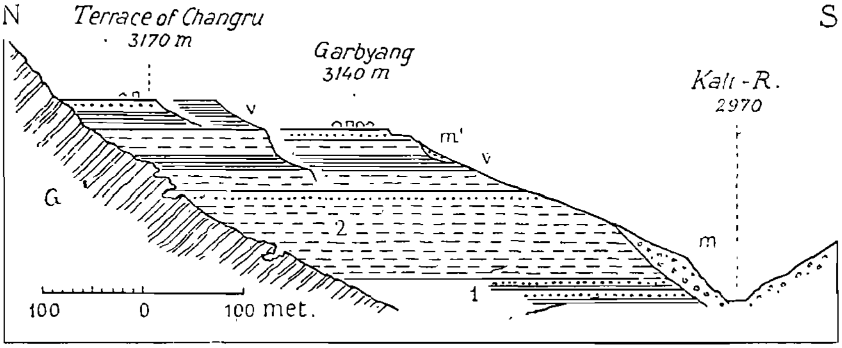


Fig 77. The Pleistocene Lake Deposits of Garbyang.
G = Garbyang series (Cambrian): 1 = lower gravels; 2 = Compact sandy loam; v = varves; mm' = ground moraine.

A microscopic test made by Prof. Dr. HELMUT GAMS of Innsbruck, who was on the lookout for pollen in the varved clay, had a negative result.

Only at the circus on the NE side of Garbyang, under the protection of the spur 11387', the varve deposit reaches the top level of the former lake. The small village is dangerously situated on the south-western edge of the top-gravel replacing the varves (Phot. 16, Pl. X).

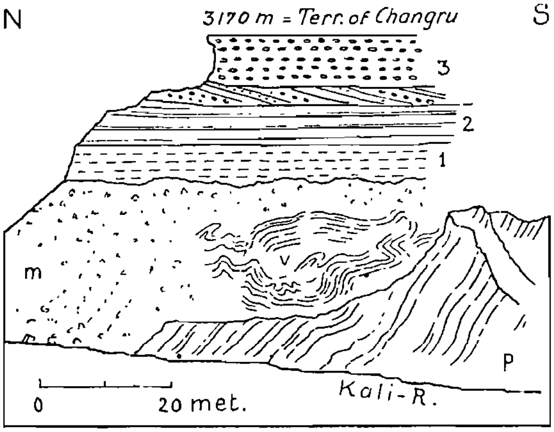


Fig. 78. A Relic of the Lake Deposits at Kaua Talla, Kali Gorge above Garbyang.
P = Phyllite (Cambrian); m = Moraine mixed with talus, enclosing V = varves crumpled by subaquatic sliding or glacial pressure; 1 = Compact loam; 2 = Varved loam; 3 = Gravel, lower part with diagonal bedding.

On the Nepali side opposite Garbyang, we found ground moraine with interbedded gravel, as far up as 50 meters below the Garbyang level; then follows lake loam, covered with 2 meters of gravel up to the Garbyang level. Apparently this ground-moraine is older than the lake loam.

In no place at Garbyang did we find moraine walls above the former lake level.

If we follow the Kali river upwards, we find an interesting relic of the lake filling at Kaua Talla (Fig. 78).

At the confluence of the Kali and the 5—8 times larger Kuti Yangti, and further up to Gunji, the broadening valley is made of gravel, shaped to terraces at different levels. The village of Gunji is on the highest one. The barometric elevation, given on the topographic map, is 10310' = 3145 meters,

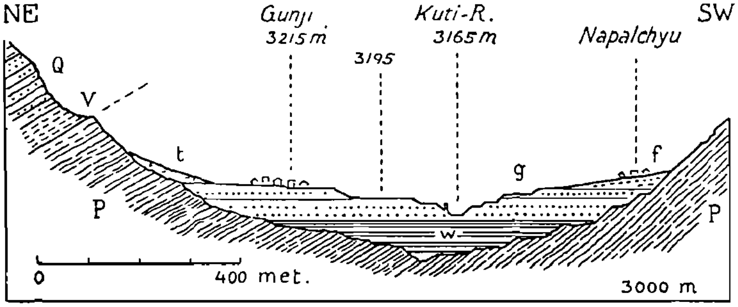


Fig. 79. The Gravel Terraces of Gunji.

P = Phyllite of upper Garbyang series (Cambrian); V = Violet shale (lower Silurian); Q = Quartzite, Silurian; w = Level of Garbyang varve deposits; g = Gravel filling; t = Talus; f = Fan deposit of Napalchyu side river.

whereas our instrument indicated 3175 meters, according to which the former sea level with the supposed varves would be just below the Kuti river (Fig. 79).

Further up, the Kali valley cuts in V-shape across the complicated folds and thrusts of Silurian to Jurassic age, as described above, then widens again above Kalapani. The trail along the north side of the river follows gentle foot hills of upper Triassic shale, covered with moraine and talus until we reach a great moraine wall of recession at the mouth of the Lilinthi glacial river (Phot. 20, Pl. XI). Behind it is the flat valley bottom of Lilinthi grazing ground. The river has cut a gorge across this terminal moraine, the top of which is at 4320 meters (barometric).

Above Sangcham encamping ground we come to lateral moraine walls at 4850 meters and reach the last moraine coming from the north side of Lipu Lek at 5050 meters, only 80 meters below the pass.

Lipu Lek is the lowest point of the Indo-Tibetan watershed. Although the mountains around it reach 5500 -5600 meters, there is only a small firn field left of the great former glacier. True, there is more firn snow on the Tibetan (= south-east) side of the pass, but even there no real glacier is formed. The summits of 5500 meters hardly reach the snow line.

Tinkar Lipu (Nepal)

This north-eastern part of Nepal has hardly been surveyed at all by the Indian topographers and is designed by hatching, the whole being completely misleading. We refer to Fig. 46 and the topographic improvement on our map 1 : 650.000, without entering into details. Limited time and bad weather prevented us from making a new topographic survey. We have, however, to describe some geological discoveries.

a) Tectonics and Stratigraphy

East of Garbyang, the Tinkar river has cut its way in V-shape partly along, partly across the upper Garbyang phyllites, which dip regularly about 45° to N.

From the little Chorten 2 km E of Tinkar, a branch of the valley turns to the north across the strike. The violet basal Silurian is recognized on the western walls above the primitive shepherd huts of Dongang. It must pass below the moraine on the trail.

Tectonical complications and bad weather prevented us from clearing up the whole section. At Tinkar Lipu, 5200 meters, we are at the pass to Tibet. There A. Gansser discovered in the black shale the fine Norian fossils which are the key to our understanding of the stratigraphic and tectonical section (Fig. 80 and Phot. 19, 21, Pl. XI).

The pass is weathered out of the upper Triassic shale, while the beautiful ice-clad peak Phung-Di (6000 meters), on its SE side, and Sabu (5800 meters) are formed of Silurian quartzite, with an abnormal dip of 50° to NW. However, on the whole, the stratigraphic position is normal. But the details of the lower Triassic are extremely complicated by thrustfolding and

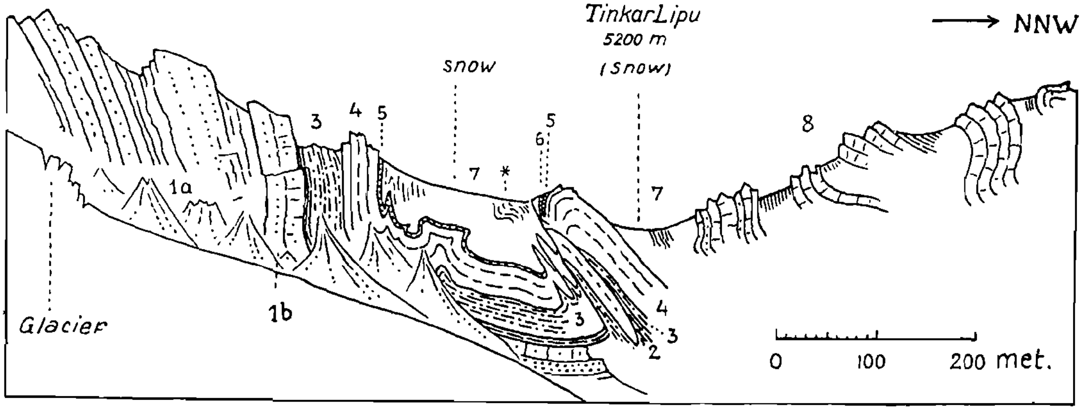


Fig. 80. Section across Tinkar Lipu.
1 Muth series. a) Limestone and quartzite; b) 30 meters dolomite-quartzite; 2 — Productus shale (traces); 3 = Chocolate shale (Eotrias); 4 = Kalapani limestone; 5 = Sandy limestone with ammonites, 2 meters; 6 = Foliated sandstone; 7 = Black shale with black limestone flags and a rich Norian fauna (Kuti shale); 8 = Kioto limestones with shales, the lower oolithic.

crumpling with abnormal strikes. Thus the thrusted little anticline of Kalapani limestone, with its extremely fossiliferous cap layer pitches towards W and disappears rapidly below the upper Triassic shales. The latter are doubled. The southern syncline (below * in Fig. 80) has even the shape of a sack, the strike of the Kalapani limestone on its E-side being at a right angle to the normal north-western strike. It is therefore impossible to represent the true structure by one section. The details are shown in Fig. 81.

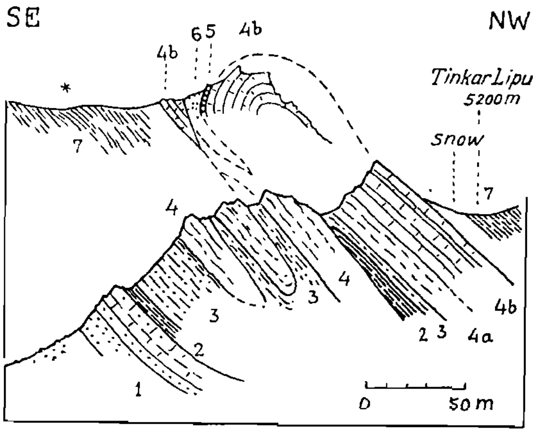


Fig. 81. Details of Triassic on Tinkar Lipu. Nrs. 1—7, see Fig. 80. The stratigraphic peculiarities are as follows:

1 = The top of the Silurian series is a massive dolomite-quartzite of 30—50 meters;

2 = The Productus shale (Kuling shale) is primarily rudimentary, and squeezed in addition, the maximum thickness of the black shales being about 5 meters;

3 = The Chocolate series (shaly clay-iron stone of chocolate brown weathering) is normally about 30—40 meters thick.

4 = The Kalapani limestone in its lower part (10 meters) is easily recognizable by its yellow to orange or rusty patches of weathered ankerite in the dense blue limestone and its nodulous layers, with some ammonites. The upper part (20 meters) is a dark well-bedded limestone which contains some brachiopods, corals and fragments of crinoids. The patchy limestone is piled up 4 times, with 3 visible thrust planes between. These scales dip 40° to W 30 N.

5 = The top of the Kalapani limestone is the richest fossiliferous horizon. It is a fine gray sandy limestone of 1—2 meters, full of thick involute and also thin sharp-edged ammonites, the latter with diameters up to 35 centimeters.

6 = Foliated gray sandstone with oolitic and sandy calcareous flags, 10—12 meters.

7 = Black shale with calcareous flags, locally rich in beautifully preserved deep sea fauna, partly of dwarf fossils, especially cephalopods of Norian age; normal thickness over 100 meters.

8 = The next higher horizon is an oolitic gray limestone of upper Triassic.

b) Chemical and Microscopic Remarks

The lower Triassic division No. 3, of characteristic brown weathering was called chocolate limestone already 40 years ago in the northwestern region. Part of it is, how-

ever, more of a silicious shale than a limestone. An analysis yielded the following results of the compact part:

Insoluble	51.2 %
H_2O	1.27
CO_2	21.80
CaO	15.53
MgO	7.04
FeO	3.23
	100.07

Under the microscope, the same specimen is of micro-granular structure, chiefly made of calcite with relics of a dense groundmass and numerous imperfect ankeritic calcite rhombohedrons. The expected quartz sand is absent.

The patchy Kalapani limestone Nr. 4 is of an interesting mineral aspect (Phot. 75, Pl. XXV). The bluish gray limestone, of a dense structure, is full of straight or slightly curved tiny calcitic stalks up to 0,25 mm in length. They are partly doubled, the transverse section being a ring. They may be small algae. The yellowish to rusty brown patches, as was to be expected, are made of a mosaic of fine autogenous ankerite or ankeritic calcite rhombohedrons. They are usually below 0,1 mm, but some of them reach 0,25 millimeters. Their well-defined limonitic contours are apparently the residue of the impure calcareous material of which they were formed during diagenesis. All these tiny crystals, also those of concentric growth, show uniform extinction under crossed Nicols. The ground mass of the mosaic is dense lime.

The resemblance of this patchy limestone to the Helvetic Schiltkalk of Argovian age, as was to be excepted from their common aspect, is striking.[1]

A chemical test of the yellowish brown part of the rock formed of the ankeritic rhombohedrons yielded the following result:

Insoluble (Silica and clay) . . .	51.20 %
FeO	3.23 %
CaO	15.53 %
MgO	7.04 %
CO_2	21.80 %
H_2O	1.27 %
	100.07 %

The dense black ammonite limestone of the Kuti shales Nr. 7 shows under the microscope a wealth of gastropod- and cephalopod embryons, but no distinct foraminifera. In addition, there are long tiny stalks of dense brown lime with symmetric transverse fibres, of unknown origin.

c) **Fauna** (Determinations by A. JEANNET)

From the lower part of the chocolate series (Nr. 3) were collected out of scree the following Eo-Triassic ammonites:

? *Meekoceras* sp. ind.
Ophiceras demissum OPPEL
Ophiceras cf. demissum OPP.
Anakashmirites nivalis DIENER
? *Glyptophiceras Kashmiricum* SPATH

From the lower nodular part of the Kalapani limestone (with ankeritic patches, 4a of Fig. 81), are

Griesbachites sp. nov.
Gymnites cf. *Sankara* DIENER
? *Japonites* sp. cf. *Dieneri* MARTELLI
Siliceous sponge

Except Griesbachites, which is a Carnic fossil, all are Anisian types. From the dense, dark blue upper Kalapani limestone (4b of Fig. 81) are:

Traumatocrinus sp. (numerous fragments)
? *Spirigera hunica* DIENER

which probably are lower Ladinian ("Daonella limestone").

[1] See ARNOLD HEIM, Monogr. d. Churfirsten, Beiträge z. geol. Karte der Schweiz n. F. Lfg. XX, part 3, Fig. 156 p. 566.

From the Sandy Limestone (Nr. 5 of Fig. 81) forming the top of the Kalapani limestone and corresponding in its stratigraphic position to the Tropites Limestone of DIENER were gathered in place the following numerous cephalopods with many new species, which shall be described by Prof. JEANNET:

? *Halorites* sp.
Dimorphites sp.
Anatomites cf. *Brocchi* MOJS.
Molengraaffites cf. *compressus* WELTER
Molengraaffites sp.
Anatropites sp.
Styrites cf. *signatus* DITTM
Clionites sp.
? *Beyrichites* sp.
Thisbites sp.
Paratibetites cf. *Tornquisti* MOJS.
Paratibetites Adolphi MOJS.
Paratibetites angustisellatus MOJS.
Hauerites cf. *rarestriatus* HAUER
Polycyclus sp.
New genus to be described.
Metacarnites sp.
Sirenites cf. *elegans* MOJS.
Sirenites cf. *Alixis* DIENER
? *Welterites* sp.
Cladiscites cf. *pusillus* MOJS.
Arcestes cf. *Piae* DIENER
Arcestes sp. nov.
Arcestes sp. div.
Gymnites sp.
Pinacoceras sp. nov.
Placites Sakuntala MOJS.
Placites polydactylus MOJS. var. *Oldhami* MOJS.
? *Megaphyllites* sp.
Discophyllites aff. *Ebneri* MOJS.
Discophyllites sp.
Proclydonautilus cf. *acutilobatus* DIENER
Orthoceras sp.
Atractites sp.
Halobia styriaca MOJS.

We thus have here an almost exclusive cephalopod horizon, the Arcestidae (Carnic) being preponderant. But there are also the Noric *Paratibetites*. In the writers idia it is a condensed product of Carnic and Noric age similar to the *Tropites* beds, although no true *Tropites* are present at Tinkar Lipu.

The black limestone flags of the Kuti shale (Nr. 7 of Fig. 81) have furnished the following Cephalopodes, most of which of a fine preservation:

Halorites cf. *procyon* MOJS.
Halorites sp.
Isculites sp.
Juvavites sp.
Anatomites cf. *crasseplicatus* MOJS.
Anatomites cf. *Bambanagensis* MOJS.
Parajuvavites cf. *Jacquini* MOJS. (young)
Parajuvavites cf. *Buddhaicus* MOJS.
Parajuvavites cf. *minor* MOJS.
Parajuvavites sp. nov.
Parajuvavites sp. div.
Metasibirites cf. *spinescens* HAUER
Thetidites Huxleyi MOJS.
Thetidites sp.
Milites sp
Cycloceltites sp.
Clionites Woodwardi MOJS.
Clionites sp.
Steinmannites sp. nov.
Cyrtopleurites Herodoti MOJS.
? *Welterites* sp.
Sandlingites cf. *Archibaldi* MOJS.
Proarcestes sp.
Placites Sakuntala MOJS.
Discophyllites sp.
Megaphyllites sp.
Orthoceras sp.

Numerous tiny Gastropods, Pelecypods and Brachiopods.

This fauna is characterized by the numerous *Parajuvavites* and *Steinmannites*, and is frankly Noric.

From the overlying shales, in the talus, was found *Monotis salinaria* BRONN, also a Noric species.

d) Glaciation (Fig. 46)

Following the Tinkar valley upwards, we find towards east and above the gravel terrace of Changru a first moraine wall of recession at 3450 meters, and a further one preserved on the north side of the valley at 3530 meters.

The small village of Tinkar, the highest of north-western Nepal, is situated on an inclined terrace at 3700 meters. There, several branches of glacier rivers come together, each furnished with end moraines or retreating stages:

a) in the valley coming from the north (peak 20276′ called Thimbu) at 3970—4150 meters, at 4430 meters and about 4800 meters. The latter is of a subrecent stage, situated about 1 km from the end of the small southeastern Thimbu glacier, south of the pass 5100 meters which leads from Tinkar to Kalapani.

b) A large lateral moraine at 3800 meters forms a terraced spur in the SE, opposite Tinkar (Phot. 17, Pl. X).

c) Two kilometers east of Tinkar, a sacred little Chorten is placed on a moraine, above the junction of the glacier rivers coming from NE and SE, at nearly 3800 meters altitude.

d) Turning thence north towards Tinkar Lipu, two moraine walls are found on which the poor shepherds stone huts of Dongang are situated at 4070 and 4180 meters. Two kilometers further north follow hills of 4540 and 4620 meters. Behind them extends a level flat (filled lake?). An extraordinary moraine, rising stair-like, was seen at a distance farther northward towards the pass leading to Lilinthi. This pass would also be most interesting tectonically.

A large final moraine of horse-shoe shape, with white quartzite blocks on the path to Lipu Lek is at an altitude of 4800 meters, the crest being at about 4850.

All the high peaks of 6000 meters and more, forming the crest and boundary of Nepal and Tibet, south of Lipu Lek, are sending small glaciers to the collecting Tinkar valley, especially those of Katscharam (20279′) and south of it.

A fairly large and clean glacier comes down from the north side of Phung-Di (see Photo 71 and 73 in 30). It ends at about 4850 meters on the Tibetan side.

The region of Kuti, Kumaon

a) Tectonics and Stratigraphy

On the trail up the Kuti valley, the village of Nabi is passed at the foot of the magnificent peak 13944′. Its walls are so beautifully banded in brown and white and black, that the stratigraphy is clear at a distance (Fig. 82).

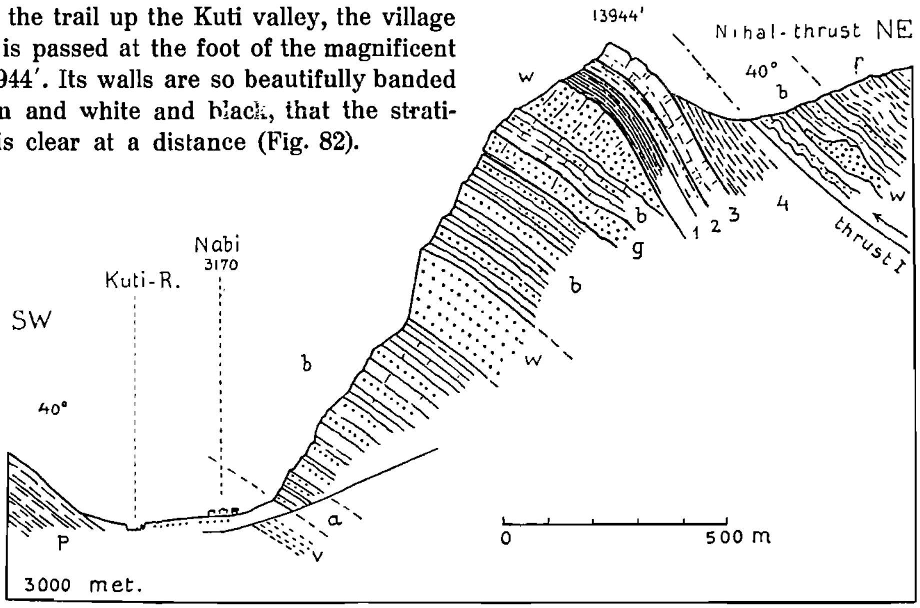


Fig. 82. The Coloured Walls of Nabi Peak 13944′, Kuti Valley, as seen at a distance. Thickness of the formations approximate

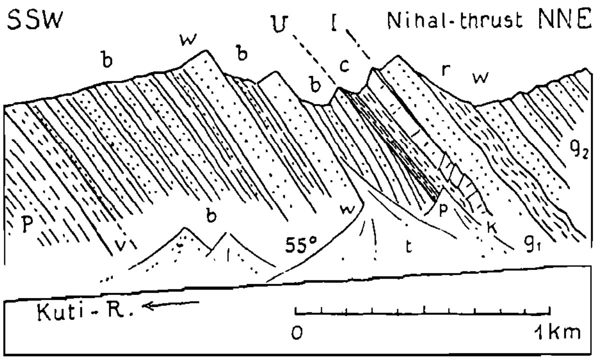
P = Calcphyllite (upper Garbyang series, Cambrian); v = Violet shale, r = red shales (of lower Silurian); a = Banded quartzite and shale in brown, black and white; b = Rusty brown quartzites with dolomite and limestone layers; w = White Muth quartzite, g = Gray quartzite; 1 = Productus shale, Permian; 2 = Chocolate shale (lower Triassic); 3 = Kalapani limestone (Muschelkalk); 4 = Kuti shales, Norian.

The sequence of the imposing SW face seems to be normal and non-reduced, from the phyllite over the violet lower Silurian to the huge mass of banded Muth quartzites and dolomites. Their normal thickness, the average dip taken as 30°, would be 1100 meters (supposing the elevation of Nabi peak 13944′ and Nabi village 10460′ of the topographic map 62 to be correct). On the west side of Nabi peak, the white top-quartzite is seen pinching out northward. It is one of the rare places where a local unconformity, of apparently stratigraphic origin, is visible in this region (Fig. 82). Above it follows the normal Permian-Triassic sequence which is cut off by the thrusted Silurian with its bright red Crinoid shales, recognized at a long distance. Whether the basal quartzites of the thrust sheet are in a normal position (Ordovician) or reversed, we were not able to ascertain.

At the next village, Nihal, the Triassic comes down to the river and follows it underneath talus, in order to cross the river 3 km further up, where the thrust is nicely visible on the SW side of the valley (Fig. 83). We shall call the thrust mass above Nihal the Nihal thrust sheet.

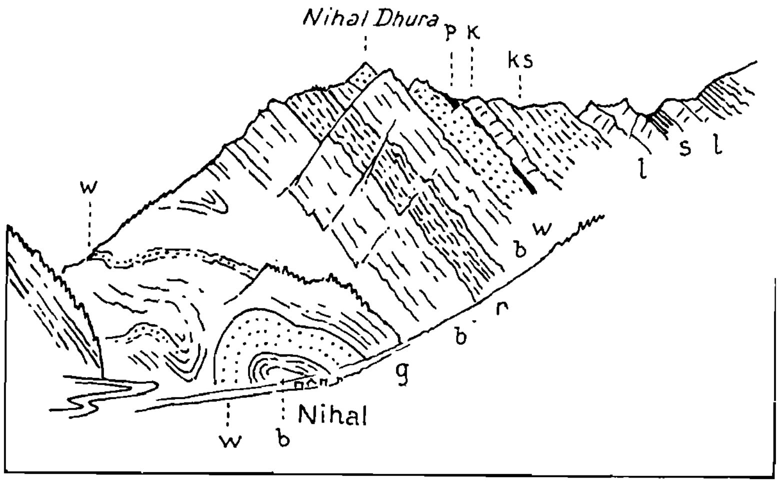
Fig. 83. The Structure of the Nihal Thrust Sheet, SE side of Kuti Valley above Nihal, as seen towards WNW.

Lower series: P = Pre-Silurian phyllite (upper Garbyang series); V = Violet shale; b = Brown quartzites and dolomites, Muth quartzite; w = White quartzite, Muth quartzite; p = Productus shale; C = chocolate shale; K = Kalapani limestone (Trias). Upper series: g = Gray to pale violet quartzite (Ordovician?); r = Red and variegated shales (lower Silurian); w = White Muth quartzite; U = Unconformity (?); I = First thrust plane of the Northern Ranges (Nihal thrust).



Above Nihal, on the NE-side of the river, intense secondary folding is visible in the core of the thrusted Silurian series. It seems to be doubled: The red Silurian shales (r) form a band above the folded body of quartzites and are normally overlain again by the quartzitic Silurian series and the Triassic sequence in addition. The Muth quartzite forms the Nihal Dhura (Fig. 84). This peak thus corresponds exactly to the Kalapani peak 17634′.

Fig. 84. View of Nihal from SE
r = Red calcareous shale (Lower Silurian); b = Brown quartzite and dolomite; w = White quartzite; g = Gray to violettish quartzite; P = Productus- and chocolate shale; K = Kalapani limestone; Ks = Kuti shale, l = Kioto limestone; S = ? Spiti shale, Jurassic.



Intense secondary folding is also seen south of Kuti (Fig. 85). The Paleozoic sequence of the Nihal thrust sheet may be noted approximately as follows from below:

1. gray, violettish and white quartzite 100—150 meters
2. red shale, 100 meters, sharp limit to
3. gray to violettish quartzite, 400 meters
4. violet to red and gray shale 200 meters
5. brown quartzite and dolomite 800—900 meters
6. white quartzite (= Muth quartzite) 150 meters.

Numbers 4—5 are well exposed above the trail 3,5 kilometers south of Kuti. There the following subdivisions, dipping 45° to NE, were observed from below:

4a Red calcareous shale, about 150 meters, passing into
4b pale variegated to gray slaty limestone, about 50 meters; passage within a few meters into
5a rusty yellow weathered dolomite with quartzite in thick beds, forming a wall, about 50 meters.

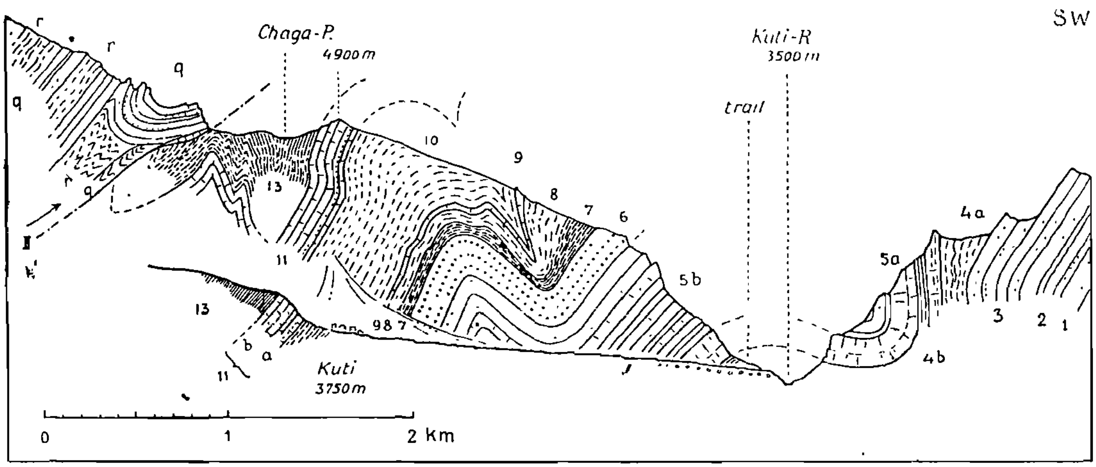


Fig. 85. Section of Kuti.
1 = Gray to violet quartzite (Ordovician?); 2 = Red shale; 3 = Like Nr. 1; 4 = Variegated shale and limestone; 5 = Brown dolomite and quartzite (upper Silurian); 6 = White Muth quartzite; 7 = Productus shale; 8 = chocolate shale; 9 = Kalapani limestone, reduced; 10 = Kuti shale; 11 = Kioto limestone with quartzite layer; 13 = Spiti shale, upper Jurassic. Above thrust II : r = red shale; q = Quartzite, Silurian.

We now come to Kuti, 3750 meters, the highest village of the Kumaon Himalaya, which we made our second headquarter. Thence we first visited the north-eastern side of the valley, rising up towards the Zaskar Range.

The normal succession at and behind the village, in ascending order (Fig. 85) is:

10. Kuti shales: black, micaceous. Total thickness 400—500 meters. Upper part with thin beds of micaceous sandstone; passage to
11a. 8 meters of brown sandy limestone beds, passing to
b. 30—35 meters of well-bedded gray limestone, partly dense, partly oolitic.
c. 12 meters of white quartzite layers
d. 100—120 meters of well-bedded, compact limestone, dense and dark blue inside, forming a white wall. Top layers with ripplemarks. Sharp limit (discontinuity) to
13. several hundred meters of Spiti shale.

Curiously enough, Griesbach did not notice the occurrence of Spiti shales in the eastern part of Kumaon and mapped them partly as lower Triassic, partly as Carboniferous. At Kuti, they are, however, of wide extension and represented by their characteristic ammonites and

belemnites, which are found inside the siliceous concretions. They are more flinty in the lower part and more of a clay-iron stone in the upper part, where also layers of such material are found in the black clay shale. The fossils are frequently pyritized. It is impossible to establish stratigraphical subdivisions. (See list of fossils in the conclusive chapter.)

A chemical test of a black concretion around an ammonite gave the following result: 72,4 % of insoluble material (silica and clay), about 10 % of iron and 2—3 % of carbonaceous matter. The corresponding slice, although very thin, is nearly isotropic and partly amorphous. There are few micro-organisms, hardly to be recognized, beside a few tiny quartz grains, but numerous small imperfect calcite rhombohedrons.

Already at a distance a sharp line is seen above these Spiti shales which form an undulated gentle slope with pasture, rich in bright yellow and red flowers *(Potentilla argyrophylla)*. The walls above, as far as we climbed them (up to 5000 meters) are made of folded and repeated Silurian red shales and quartzites! We are thus in presence of the second great thrust of the Northern Himalaya Ranges, which is the continuation towards WNW of the thrust of Lilinthi-Tera Gad. (Phot. 26, Pl. XIII.)

Beautiful exposures of this thrust are seen SE and NW of Kuti. We first climb on the synclinal Spiti shales to the pass at 4800 meters, 3—4 kilometers SE of Kuti, called Chaga pass by the natives (Fig. 85-86). About 1 kilometer before reaching it, the upper Triassic Kioto limestone comes up again on the NE side of the little valley washed out on the soft Spiti shales, forming a wall of about 100 meters height, at a dip of 70—80° towards SW. This limestone is cut off at a right angle by the thrust plane Nr. II.

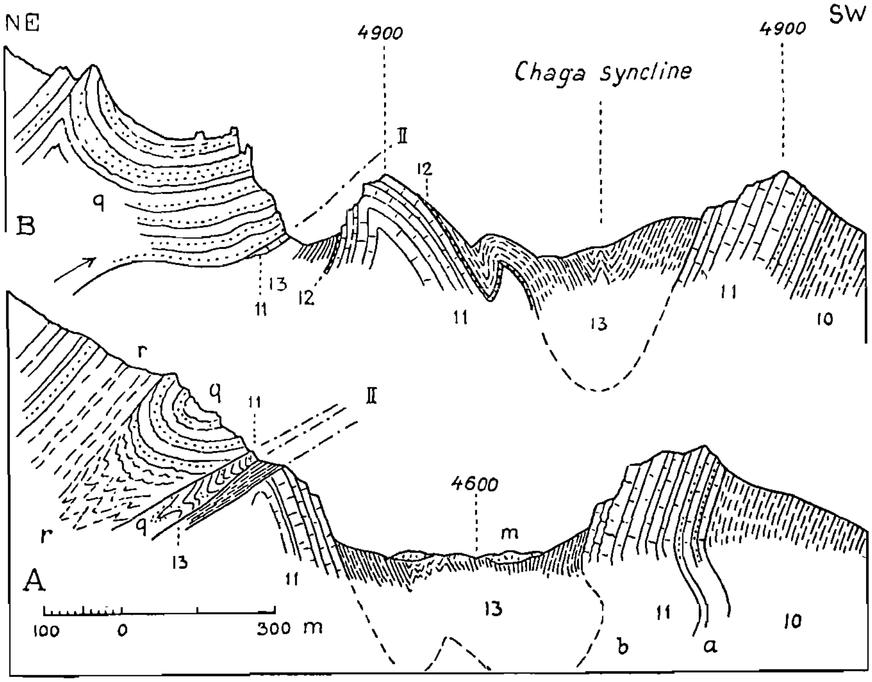


Fig. 86. Details of the Thrust II at Chaga Pass.
For numbers of strata see Fig. 85; 12 = Ferruginous oolite, Callovian; A = 0,5 to 1 kilometer NW of the pass; B = a few hundred meters SE of the pass.

The thrust, on the NW side of the Chaga pass is subdivided into 2—3 sliding planes with sliding packs between, of quartzite and Triassic limestone. At the pass itself, only small fragments of this squeezed limestone remain, broken and mylonitized. The thrust plane of the Silurian quartzite descends towards SE into the next side valley, then rises again with a dip of 45° to NE to the glaciated crest NE of Nihal Dhura. Although visible only for a few seconds

through rain and clouds, the contact was recognized from Chaga pass in perfect clearness. The thrusted Silurian rocks become still more compressed into narrow folds, while the Spiti shales above the limestone Nr. 11 are reduced to a black furrow.

The Chaga syncline, forming a zone of black shales of about half a kilometer at the pass, becomes doubled on its SE side, as shown in Fig. 86B. At an axial rise of as much as 20—30°, a pointed-arch anticline of upper Triassic limestone rises out of the Spiti shale syncline, forming a new crest and peak. A closer examination resulted in an interesting little discovery: Above the thick-bedded Kioto limestone, just on the anticlinal crest, follow with a passage.

a) 10 meters of dark well-bedded marly limestone
b) 5 centimeters of ochre (indicating a former zone of oxydation). Sharp limit to
c) 3,0 meter of calcareous ferruginous oolite with belemnites and gastropods, passing to a
d) 10 centimeters belemnite layer of clay-iron stone with ferruginous ovoides, deeply weathered, full of *Belemnopsis* and rare ammonites. Sharp conformable limit to
e) black Spiti shale.

In the talus of *c* a good specimen of

Subgrossouvria cf. gudjinsirensis WAAGEN

was found, which points to the Athleta zone (Upper Callovian). The Callovian age of the ferruginous oolite also is confirmed by the ammonites found later at Laptal 85 km farther NW.

The importance of this occurrence will be discussed later. But another fact is to be emphasized even at this point: the conformable discontinuities of the upper and lower boundary of the ferruginous oolite bed, and the absence of this Jurassic horizon on the SW limb of the Chaga syncline at the pass and thence towards NW.

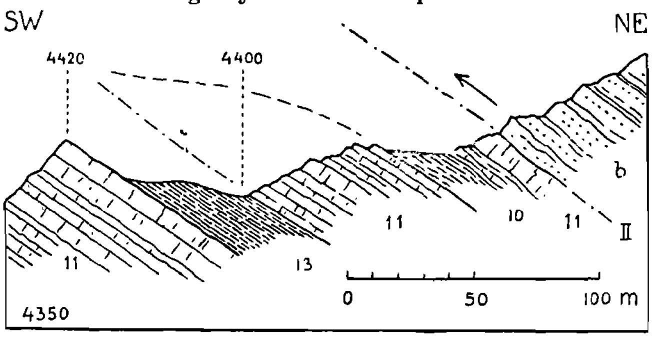


Fig. 87. Detail of the Thrust Nr. II at 2,5 km NW of Kuti. 10 = Kuti shale (or Spiti?) 11 = Kioto limestone, with sharp discontinuity to 13 = Spiti shale; b = thrusted brown quartzite (Muth, or older).

Climbing now to the symmetrical gap NW of Kuti (4420 meters), we not only find the thrust plane II of Chaga pass well exposed again, but also two or three upper Triassic sheets, sheared off by the thrust plane and dragged ahead below it (Fig. 87).

These drag-sheets are less crushed than at the Chaga pass, except the uppermost one. The lower one is squeezed out entirely half a kilometer farther NW.

Climbing up the avalanche-couloir NE of Kuti, we noted red shale in abundance, up to 4800 meters, with many repetitions in the shape of compressed minor folds; but the Monsun weather was too bad to obtain an idea of the greater subdivisions of this thrust sheet Nr. II, nor could we find out if the magnificent peak 21130' on the Tibetan border, called Shangtang by the natives, the highest of the Zaskar range, forms part of the thrust mass Nr. II or of an even higher one.

Before we go to the SW side of Kuti valley, we have to look closer again to the normal series of the Nihal thrust sheet Nr. I.

From the trail W of Kuti towards SE, a peculiar structure is seen on the walls: The Kalapani limestone between the two bodies of shale forms a secondary syncline in the shape of an upright or even backward leaning wedge (Fig. 85 and Phot. 27, Pl. XIII). While the basal Productus shales (7), the basal Triassic with 3 meters of ferruginous limestone (corresponding to the *Ophiceras* stage of GRIESBACH) and 50—60 meters of chocolate shale are well developed,

the Kalapani limestone is reduced to a small though prominent yellowish band of 10—20 meters. Possibly the upper part is stratigraphically missing, the boundary to the black Kuti shales being a sharp conformable discontinuity.

Now we go to the little hill in the nicely terraced barley and buckwheat fields, half a mile south of the village, on which are the ruins of a former castle. It is the direct north-western continuation of the locality we described above, and formed of the lower Triassic sequence at a regular dip of 60° to NE (Fig. 88).

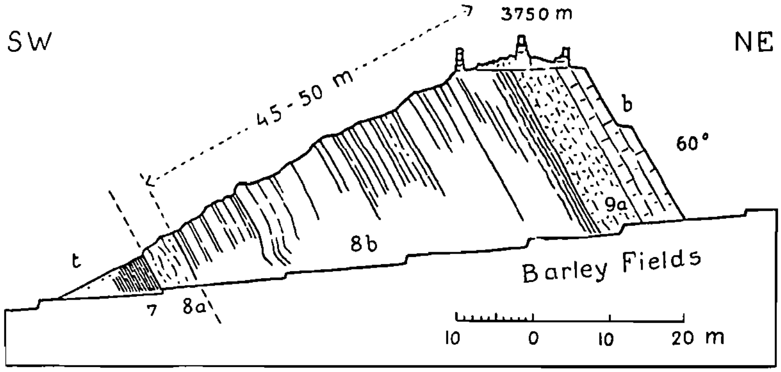
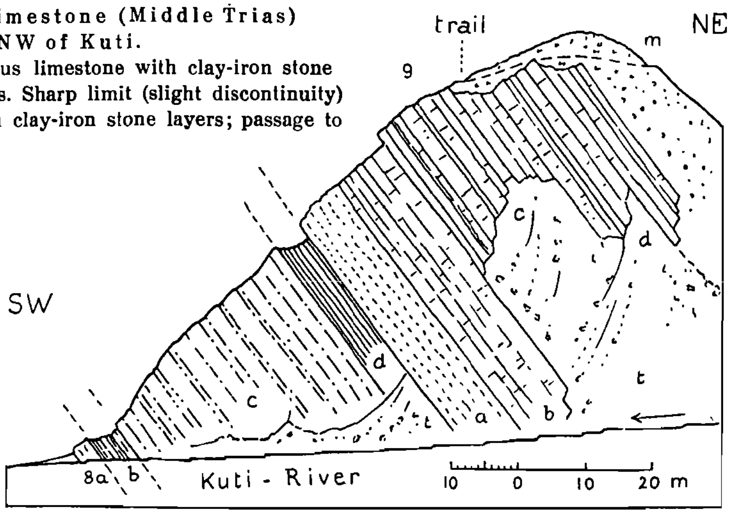


Fig. 88. The Stratigraphic Succession at the Castle-Hill of Kuti.
7 = Productus or Kuling shale, lower part covered by talus. Sharp limit to
8a — 5,0 meter of wavy ferruginous limestone, in its lower part layers of clay-iron stone, with numerous ammonites; sharp limit to
b = 45—50 meters of clay-iron stone with slaty intercalations. Sharp contact to
9a = 6 meters limestone-lumachelle with brachiopods and rare ammonites, passing into
b = 5 meters light gray compact limestone with broken shells of echinoderms, bivalves and ammonites.

We thus have here a complete series of the basal Trias, with several concordant "small discontinuities" of sedimentation.

A complete and normal section of the Kalapani limestone was found 3 kilometers WNW (one hour's march) from Kuti on the river (Fig. 89).

Fig. 89. Section of Kalapani limestone (Middle Trias) 3 kilometers WNW of Kuti.
8a = 2,5 meters of nodulous ferruginous limestone with clay-iron stone layers, containing numerous ammonites. Sharp limit (slight discontinuity) to b = 4,5 meters of black slate with clay-iron stone layers; passage to c = 35—40 meters of chocolate shale, with clay-iron stone layers, well-bedded; passage to d = 5 meters chocolate shale; black slate predominent; sharp limit to 9a = 8 meters of coarse-grained limestone-lumachelle, with rusty ferruginous streaks; passage zone 1 meter to b = 9 meters of light gray compact limestone with numerous fragments of shells and badly preserved ammonites in the upper part; sharp limit (groove) to c = 18 meters of dark blue, dense, well-bedded limestone; d = 13 meters spotted limestone, like c, but more nodulous and with yellow ankerite patches; m = moraine; t = talus and mountain slide.



In the basal Triassic layer 8a the following Eo-Triassic ammonites were collected (det. A. Jeannet):

Pseudosageceras aff. *drinense* Arthaber
Ophiceras cf. *demissum* Oppel
Anakashmirites nivalis Diener
Meekoceras Hodgsoni Diener

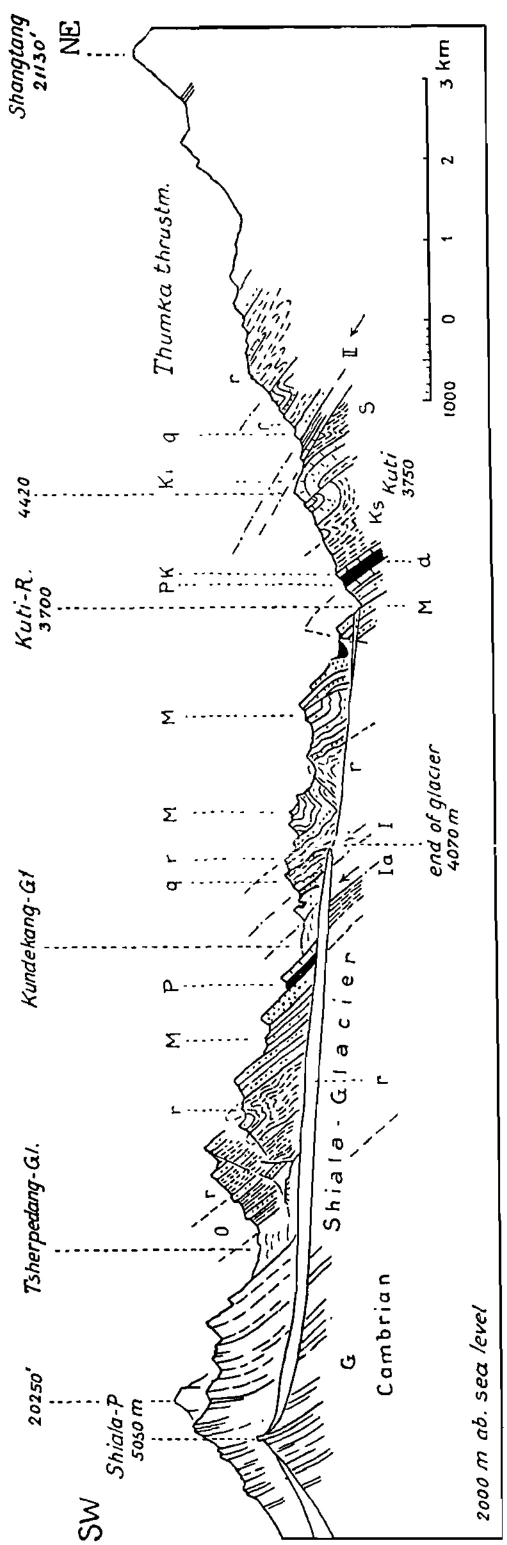


Fig. 90. Section of Kuti-Shiala Pass.
G = Garbyang series, calcareous phyllite; O = Ordovician (shale and calc. sandstone with fossils); r = red and variegated calc. shale, lower Silurian; q = quartzite in general; M = Muth quartzite; P = Productus shale, Permian incl. Eotrias; K = Kalapani ls.; Ks = Kuti shale; Ki = Kioto ls.; S = Spiti shale; d = top dolomite of Muth series.

Vishnuites sp. (cf. *pralambha* DIENER)
? *Koninckites* sp. (aff. *yudishthira* DIENER)

The upper contact of the Kalapani limestone is covered, but the basis is nicely exposed on the left side of the river, though almost inaccessible. Below 8a follow 40--50 meters of black Productus shale, which are conformably underlain by a 20 meters wall of massive dolomite, replacing Muth quartzite. This dolomite in turn is underlain by quartzite, which at the wretched bridge over the Kali, a mile W of Kuti, stratigraphically about 100 meters below the Productus shales, shows a striking aspect: the quartzitic sandstone is full of white specks of quartz. They seem to be a leading characteristic of this subhorizon of the Muth series within the district.

c) Morphology

The Kuti river, on the whole, flows through a longitudinal valley largely depending on structure and stratigraphy. In its lower part it does not, however, exactly follow the strike. We have shown that above Nabi, the basal Silurian crosses the river towards west. Similarly, 5 kilometers further up, the Nihal thrust obliquely crosses the river so that thence it runs along and within the Nihal thrust mass all the way up to its glacial sources (see our map 1:650,000).

Above the gravel terraces of Gunji (Fig. 79) the valley is V-shaped and the rocks are partly covered at their foot by dry and wet side-fans.

An interesting type of landslide must also be noted. It originates from the thrusted Silurian behind point 4420 m, 2 km NW of Kuti: a stream of rusty coloured quartzite blocks, apparently broken off gradually from the rocks on the front of the thrust and gliding down over the Kuti shales with the help of water, snow and freezing ground (solifluction). The white, yellow and brown block stream is about

a mile long and nearly reaches the river[1]. It belongs to type VI of ALBERT HEIM's "Bergsturz und Menschenleben".

Shiala (= Nama) Pass

The pass SW of Kuti leading to the Dhauli- or Darma Ganga at Sela and its glaciers have different names. The natives of Kuti call the pass Shiala Pass. It is the Nama Pass of the new map Nr. 62 B, 1″ = 2 miles, 1931. The glacier on the NE side figures under the name of Sumzurkchank on the old map Nr. 260, 1″ to 1 mile. In our new book (30) (description and photographs p. 112—114), we have used the names given by the Kuti people which we retain here.

a) Tectonics and Stratigraphy

First the folded Silurian series of the Nihal thrust sheet are crossed. A small upright anticline is passed which shows a striking though unimportant fault through the axis (Fig. 90 and 94).

The next larger anticline with red shales is slightly faulted too. Then, about 5 km in a straight line SW of Kuti we come to the basis of the Nihal thrust. It is well exposed so that it can be photographed and studied in detail (Phot. 23, Pl. XII and Fig. 91).

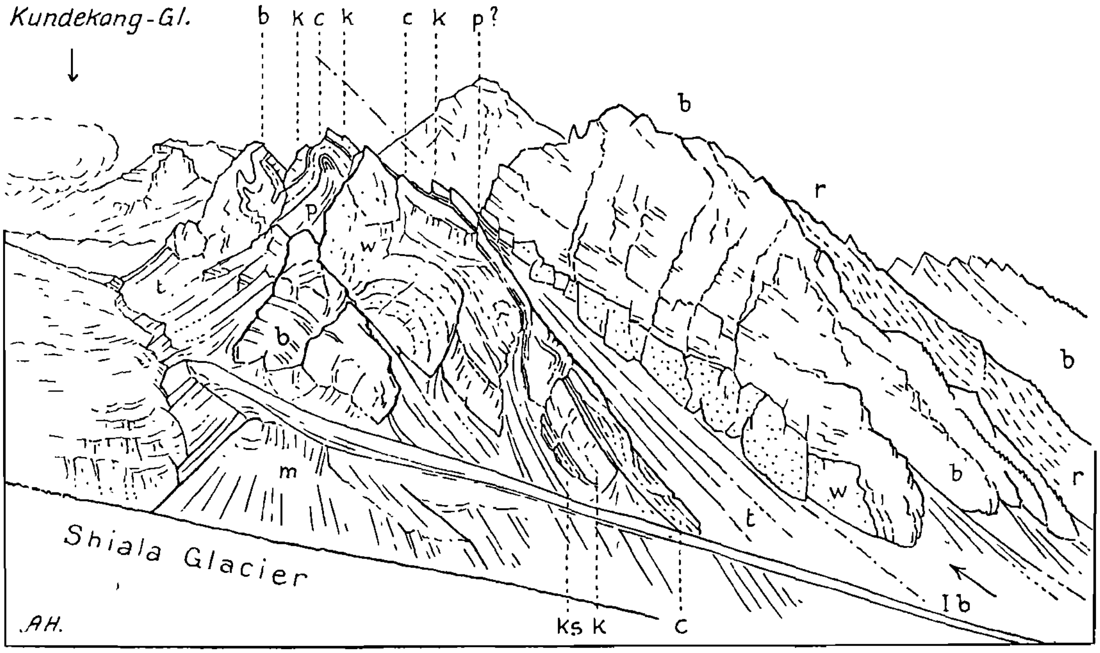


Fig. 91. The Complications of the Thrust Zone Ib at the Shiala Glacier.
View seen from SE.
r — Red Silurian shale and limestone; b = Brown quartzites (Silurian); White quartzite pointed; P = Black Productus shale; C = Chocolate shale; K = Kalapani limestone; Ks — Micaceous shale (Kuti-shale?); m = Left subrecent lateral moraine of Kundekang glacier; t = Dry talus.

The thrust plane I b of white Silurian quartzite upon black Permo-Triassic shale forms dark caves in the higher part, and is covered with talus further down where the shale must be much less reduced. But the thrust plane is very well exposed again and more easily acces-

[1] Lit. 30 phot. 109 shows the lower part of this mountain slide coming from the right (see the furrow 1,5 centimeters above the houses of Kuti).

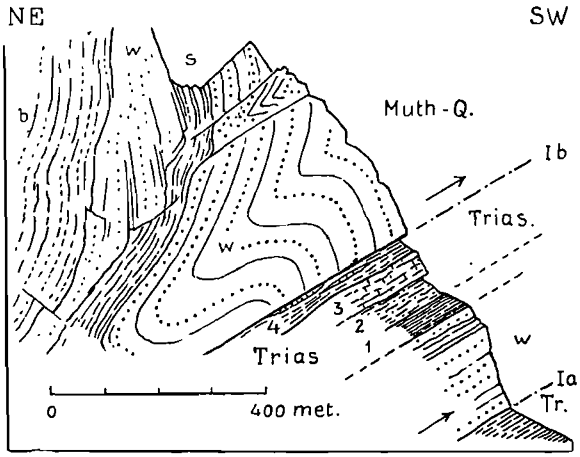


Fig. 92. Section of the Thrust Zone on the SE side of the Shiala Glacier.
b = Brown quartzite; w = White quartzite; s = Shaly intercalation; 1 = Productus shale (Permian); 2 = Chocolate shale; 3 = Kalapani limestone; 4 = Kuti shales; Tr = Triassic shale below thrust Ia.

sible on the SE side of the Shiala glacier (Fig. 92).

Thus, similar complications occur also here. Not only is the thrust doubled. The basal part of the Nihal thrust mass, formed of white quartzites, is intensely folded and squeezed. It forms a synclinal wedge which is cut off at a right angle to the stratification. The thrust plane dips about 30° to NE (Fig. 92). The details are shown in Phot. 25, Pl. XII and Fig. 93.

The thrust plane, though somewhat warped on a large scale, is a mathematical plane in detail, similar to that of the famous Lochseite near Glaris in Switzerland. It is marked by black clay with calcite of 1—5 millimeters thickness.

The thrust zone follows the two side valleys which join the Shiala glacier. The north-western one is filled with the Kundekang glacier[1]. It comes in direct contact with the Shiala glacier. From the south-eastern valley descends the Rajuju glacier, which only touches the main glacier with its frontal moraine. Both these side-glaciers cover to a great part the thrust plane Ia and the black Kuti shales underneath, of which part of the ground moraine is made. The Kundekang glacier which comes down in cataracts looks dirty and black on account of these upper Triassic shales and the mud derived therefrom.

Below the Nihal thrust Ia, the Triassic, of elegant shape, swings up again on the SW side of Kundekang glacier. The dip is 40° to NE and the superposition normal and non-reduced (Fig. 90). From the Kuti shales of Kundekang glacier we pass to the Kalapani limestone, the Chocolate- and Productus shales, which are underlain by the white Muth quartzite in perfect conformity. The latter swings up to high summits and probably forms the peak 20740 of map 62 B 1 = 4 miles or one of its neighbours. The weather was too cloudy to ascertain this.

Reviewing the thrust zone at the base of the Nihal thrust mass, we can state that the thrust is doubled. A normal Silurian to Triassic sequence is intercalated between the two thrust planes. But besides this, on the NE side of Kundekang glacier, there is an intensely squeezed and hardly recognizable anticline of lower Triassic, between the intermediate Silurian link and the upper thrust Ib (Fig. 91).

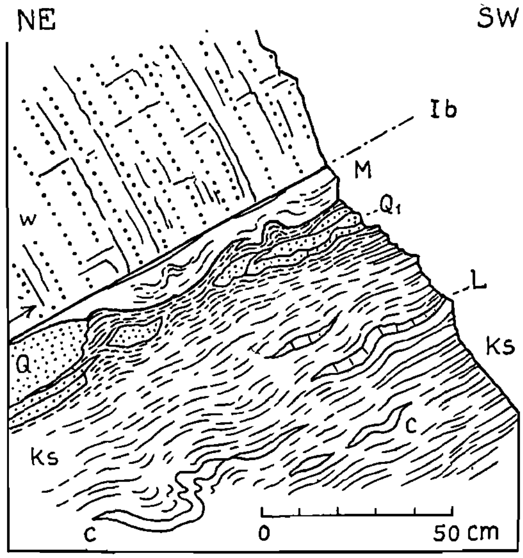


Fig. 93. Detail of the Thrust Plane Ib on the SE side of Shiala Glacier.
W = White Muth quartzite; Q = quartzite; Ib = Thrust plane; M = Quartzitic mylonite; Ks = Kuti shales (upper Triassic) with L = Squeezed limestone flags and C = Calcite veins.

[1] Names used by the Kuti people.

Proceeding farther up along the Shiala glacier to the South East, the large body of Silurian in a normal position of 45–50° north-eastern dip is crossed. Below the white massive Muth quartzite of 150–200 meters follow brown quartzites about 600 meters, then again a folded series of variegated limestones and shales of the lower Silurian, with Crinoid fragments.

Apart from duplications by folding, this series is remarkably developed as compared with Gunji. Its normal thickness may be about 800 meters. The lower part, especially on the SE side of the glacier, is more regularly stratified, dipping 55° to N 35 E, and characterized by two blood-red shaly layers, with an ochre-brown band of about 20 meters between, probably of sandy dolomite.

The pre-Silurian series is largely interrupted by side-glaciers on both sides of the main glacier. In addition, folding and faulting make the establishment of a complete normal succession almost impossible. We can say, however, that below the red Silurian follows a series af about 500 meters thickness, formed of greenish and gray marly limestones with calcareous sandstones or quartzites above and below. Both these sandstones are fossiliferous. The upper one has furnished a decidedly Ordovician fauna.

Prof. A. JEANNET has determined the following species which will be described and figured in his memoir:

A. from the sandstone in place (+ in Fig. 90);

Trilobite: *Calymene* cf. *Douvillei* MANSUY; 1 pygidium;

Gastropods: *Bellerophon* sp. ind.; 1 internal mould;

? *Trochonema* sp. ind.; 1 internal mould;

Brachiopods: *Orthis (Dinorthis) thakil* var. *striato-costata* SALTER; several ex.;

Orthothetes pecten Sow., several ex.;

Orthothetes Orbignyi DAV., 1 ex.;

Rafinesquina aff. *subdeltoidea* REED; several ex:

? *Strophomena chamaerops* SALTER; several ex.:

Sowerbyella umbrella SALTER: several ex.;

Leptaena sphaerica sp. nov.; the most abundant of the brachiopods, different from *L. rhomboidalis* WAHLENB. of the Gothlandian.

B. In the moraine was found furthermore

Orthis porcata M'COY; several ex.

The boundary to the underlying Garbyang series must pass somewhere below the side glaciers. The latter are the typical calcareous non- or slightly sericitic phyllites (Phot. 30 Pl. XIV).

From loose fragments of which the Shiala glacier is covered down to its mouth, several badly preserved and compressed gastropods where gathered. The Garbyang series seems thus to be of Cambrian age and not older.

The sharp gap of the pass 5050 meters (barometric) is made of steeply erected sericitic calcphyllite, of rusty brown weathering, at a normal strike of E 40° S. The thickness up to this point of the supposed Cambrian is about 2 kilometers, but this represents only the upper part of the Garbyang series.

If the above interpretations are correct, we should have to summarize the stratigraphic series of Shiala Pass below the Nihal thrust approximately as follows, from above:

Triassic 300 + ? meters;
Permian 50 meters;
Upper Silurian (incl. Devonian ?) 800 meters;
Lower Silurian (Upper Ordovician ?) 800 meters.
Ordovician 500 meters;
Cambrian 2000 + x meters.

b) Glaciation and Glacial Deposits

To reach the glaciated Shiala Valley opposite Kuti, one must first descend to the Kuti river, then climb 70 meters up above the bridge to a gravel terrace covered by moraine. A much higher and larger moraine corresponding to the NW side of the Shiala Valley is superposed on a gap made of synclinal Productus- and Chocolate shales, about 3950 meters above sea level and about 200 meters above the side valley (Fig. 94).

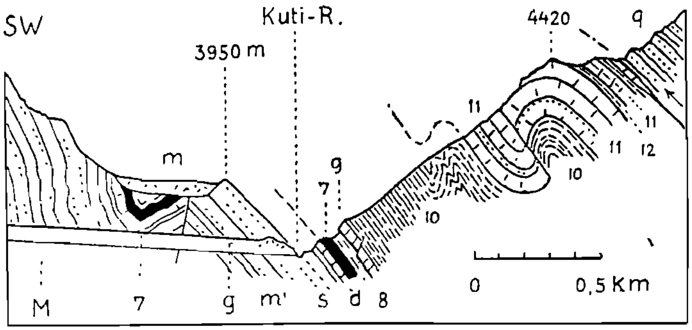


Fig. 94. Section of the NW side of Kuti.
q = Quartzite (Silurian); 7 = Productus shale; 8 = Chocolate shale (basal Trias); 9 = Kalapani limestone; 10 = Kuti shale; 11 — Upper Triassic Kioto limestone with quartzite in lower part; 12 = Spiti shale, upper Jurassic.

The mouth of the Shiala glacier is at about 4080 meters. Some 20—30 m higher and immediately before it, the lower Silurian limestone of gray to violet colour is beautifully polished and striated on convex shapes — one of the rare cases of glacial rock polish in the Central Himalaya.

The glacier is entirely covered with upper moraine, chiefly of brown weathered sandy plates of calcphyllite. On the SE-side, the characteristic greenstones of the Garbyang series too are abundant.

At about 4300 meters is the junction of the glaciated side valleys. It seems as if the Kundekang glacier passed underneath the main Shiala glacier. The high left subrecent moraine of the latter is sharply cut out by hoth present ice streams (Fig. 91).

A second left side glacier called Tsherpedang nearly reaches the main glacier at about 4800 meters. To its left side is a steep slope of ground moraine. Upon it, 80—100 meters above the Shiala glacier, the ice tongue is swimming.

The main glacier ends upwards in several lobes, forming a vast collecting field of firn-snow. It is fed also by bright hanging glaciers from the SW side of the basin (Phot. 30, Pl. XIV).

The Upper Kuti Valley and Mangshang Pass

a) Tectonics

Following the Kuti valley upwards, a deep transversal incision across the SW slope of the Zaskar Range is made by the left side valley called Thumka Gad, at 7 km NW of Kuti. It was already designed by Griesbach on his pl. 9, fig. 2. Griesbach indicates two reversed series of Paleozoic over Triassic, without recognizing the beautifully modelled thrust plane of Silurian upon Spiti shale, which he regarded as Triassic (Fig. 95 gives our interpretation; compare Phot. 29, Pl. XIII).

As seen at a distance, the red lower Silurian is present towards NE in the shape of several repetitions by folding and thrusting, passing across the glacier of Bihir Gad until 4 km north of the above section.

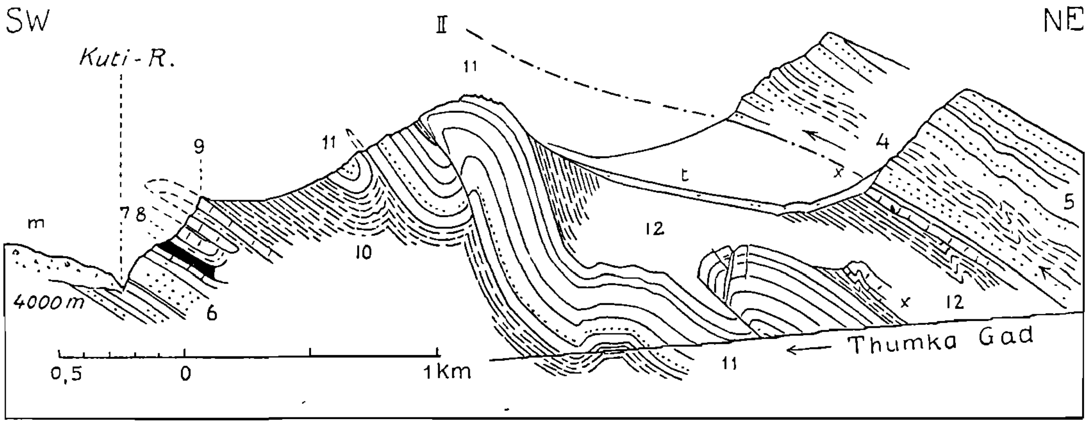


Fig. 95. The NW side of Thumka Gad.
4 = Red lower Silurian shale; 5 = Silurian quartzites; 6 = Muth quartzite with dolomite; 7 = Productus shale; 8 = Chocolate shale; 9 = Kalapani limestone; 10 = Kuti shales. 11 = Upper Triassic limestone with quartzite and oolite at the basis; 12 = Spiti shales, upper Jurassic; x = Thrust scales of limestone, probably of Nr. 11; m = Moraine; t = Talus in solifluction.

Two miles WNW of the mouth of Thumka Gad, we come to one of the few places, where vertical faults occur. Besides this, the lower Triassic is nicely doubled by local thrust-folding (Fig. 96).

The fault is of northeastern strike. Its southeastern side including the doubled Kalapani limestone has subsided about 100 meters.

At Joling Kong (Jolinka of map 260, 1" = 1 mile), the lower Triassic crosses the valley again, which further up is shaped out of upper Triassic shales and limestones. Griesbach mistook them for Paleozoic. Beautiful upright folds of Kioto limestone between Kuti- and Spiti shales are exposed near Wilsha encamping ground (Photo 34, Pl. XV).

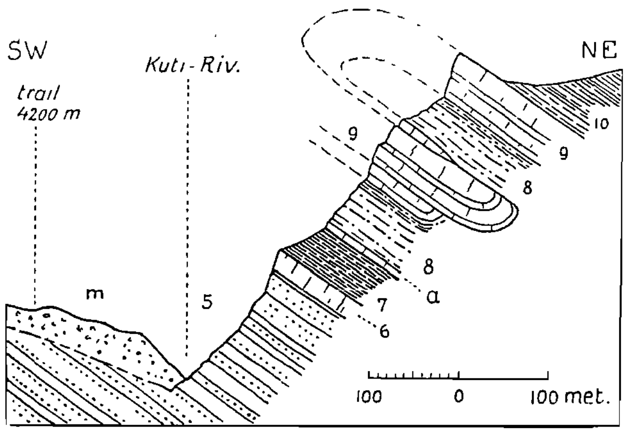


Fig. 96. Section of the Kuti Valley, 1—2 km below Joling Kong.
5 = Brown quartzite; 6 = Dolomite replacing Muth quartzite; 7 = Productus shale; 8 = Chocolate shale; 9 = Kalapani limestone; 10 = Kuti shale; m = Moraine.

The Thumka thrust (II) is again well exposed at Wilsha on the west side of Mangshang pass, and can be traced along the NE slope of the uppermost Kuti Valley for 6—7 kilometers farther towards NW. On its SW side and below it, just east of Darma Pass, the Kioto limestone forms a great anticlinal arch.

The thrust plane at Wilsha dips 30—40° towards NE.

Although the weather was very bad, we believe, after four traverses, to have established the following approximate section of the Mangshang Pass, from below (Pl. V, Sect. 9a).

1) Folded Kioto limestone covered with Spiti shale;

2) Thumka thrust mass (II) consisting of

a) 200—300 met. of brown quartzite with minor folding (Ordovician?);

b) 100—500 met. of red lower Silurian shales;

c) ? 700 met. of brown quartzite and black shales;
d) 30— 50 met. of white Muth quartzite:
e) 40 met. of black Productus shale;
f) 40 met. of Chocolate shale (lower Triassic);
g) 40 met. of Kalapani limestone.

3) Mangshang thrust mass (III)
a) red lower Silurian, folded, several hundred meters;
b) brown quartzite with black shaly layers, ? 600 meters;
c) Mangshang limestone, 150-200 meters, forming the pass and the high crest of nearly 6000 meters to the NW,
d) brown quartzite, about 50 meters (on the NE side of the pass);
e) shaly limestone of lower Silurian.

If c-e are in a normal position, then the Mangshang limestone is probably of Ordovician age.

On the whole, all these formations 2-3 dip about 30° to NE. The top of Mangshang pass (5500—5600 meters), is made of a shaly, dark bluish gray limestone (3 c), regarded by GRIESBACH as Devonian. On the north side of the pass, it is overlain by quartzite dipping 60—70° NE. Then follow firn fields down to a great glacier basin.

As far as about 10 kilometers NE of Mangshang pass, the mountains on both sides show intense folding of red shales and brown quartzites, all leaning towards SW. There, the Silurian is capped again by the flat normal Triassic sequence, which is overrun by the fourth thrust, made of red lower Silurian (Pl. V).

The mountains become more and more rounded or tabled, and covered with talus, obscuring the structure. (See further description by A. GANSSER, Tibet).

b) Morphological Features

Apart from about 7 km above Kuti, the valley abounds in moraine on its gentle SW side, while the steep NE side shows bare rocks all along. This is caused by the numerous side glaciers, which have forced the river to cut a new channel into the rock. The subrecent terminal moraines of the southwestern glaciers are nicely visible in the side valleys of Sangchuma and Nikurt at about 4300—4500 meters. The Nikurt Valley, 6 km W of the mouth of Thumka Gad, below the subrecent terminal moraine, is terraced by lateral moraine walls up to nearly 100 meters above this side river. The Kuti river has cut its channel about 70 meters deep into the moraine (Fig. 97).

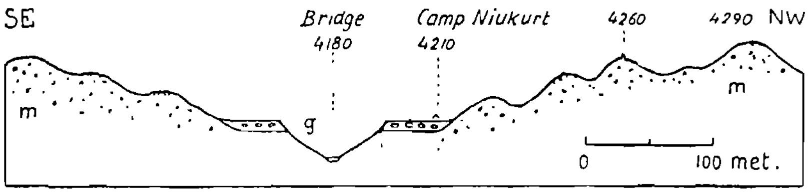


Fig. 97. Transverse Section of the Nikurt Side Valley about 4 km W of the Mouth of Thumka Gad (6 miles WNW of Kuti). m — side moraines; g = gravel terrace.

The encamping ground of Joling Kong (4350 meters) is a flat grazing place with huge blocks, two of which offer shelter from the rain. It is probably a mountain slide that fell on the former Lebong glacier, and was transported by it for a short distance. On the NW side of Joling Kong we again find a step of moraines, at about 30, 40 and 70 80 meters above the encamping ground.

The new map Nr. 62 B 1" to 4 miles, 1931, shows 7 lakes in the region from Joling Kong to Wilsha. All are but gravel flats, except two small ones. The first is immediately NW of Joling Kong at 4400 meters. It is a typical moraine lake, surrounded by the subrecent terminal moraines of the corresponding side glacier (Phot. 31, Pl. XIV). The swampy gravel flats at Rarab and Wilsha may have been former lakes.

The second lake near Ihamathi encamping ground of the old map 1" = 1 mile, called

Binchti by a native of Kuti, is at about 4500 meters, and about 300 × 400 meters large, surrounded by great moraine walls.

A great and relatively clean, unnamed glacier fills the valley south of Mangshang pass, and ends at about 5000 meters.

The great glacier on the Tibetan side, which we called Mangshang glacier, is of a different type than those on the SW side of the great watershed, and is characterized by its relative cleanliness and an almost complete absence of cracks. Its smooth northeastern end is at about 4950 meters in the shape of a flat overturned spoon (Phot. 52, Pl. XIX). The glacial river is coloured like diluted milk with some blood in it, the blood corpuscles being fine particles from the red Silurian.

As mentioned before, the surface features change rapidly towards Tibet. The wild crests and peaks are gradually replaced by rounded hills and plateaux. They are covered with partly rounded, partly angular rock fragments from the subsoil, apparently broken up chiefly because of changes of temperature and frost.

Stone flowage or solifluction, which plays a subordinate role in the Himalaya, becomes of wide distribution and importance. The stones are arranged along the grooves, where the water of the melting snow, from thawing ground and rain runs off. Polygonal arrangements, so characteristic of arctic countries, are frequent. The slopes of talus with its striation according to the shape and colour of the bottom rock may be taken for stratification as seen at a distance.

On the plateaux stones of quartzite of an intensely blue to violet metallic varnish, are frequent. This "desert-varnish" has also been encountered by the writer in the Lake Superior District of North America in regions devoid of vegetation and with great changes of temperature, and in Greenland.

The erosive basis, with the great Lakes of Raksas Tal and Manasarovar, above 4500 meters, is so high, that the force of the running water is greatly reduced. Nevertheless, the subrecent fans of the side canyons are cut out by the Mangshang river, indicating that even here the erosion is actually in a condition of accentuation.

Over the Lebong Pass to the Dhauli Ganga

a) Tectonics and Stratigraphy

(Pl. V, Sect. 9a and Pl. IV, Sect. 8)

From Joling Kong encamping ground towards WSW, we first climb over moraine and talus up and above the Joling Kong glacier (Phot. 137 in 30). Then we pass over rock. The structure is nicely visible on the walls south of the glacier. Only the core of the Kailas baba fold is covered by hanging ice (Fig. 98).

It is impossible, and also unnecessary to describe the details of structure. We refer to Pl. IV, Sect. 8 as designed directly from nature with the help of a strong Zeiss glass. Unquestionably we are in the direct northwestern continuation of the Nihal thrust, described from the Shiala Pass as Nr. I. Indeed, we also find similar complications at its basis. The Triassic sequence with its clay shales of 3 horizons, is destined for intense folding, and contrasts with the massive Silurian quartzites, from which they could easily slip off. Thus, the tectonical movements have been released chiefly by the Triassic series. Thanks to the difference of weathering and colouring, the horizons Nrs. 6—10 are relatively easily recognizable.

Here, as at the Shiala glacier, there is a squeezed fold of Muth quartzite (Nr. 6) between the Nihal thrust I b and that of the next lower tectonical series forming the overturned anticline of Kailas baba. This pyramidal summit shows on its NE side the normal middle Triassic series dipping gently towards NE.

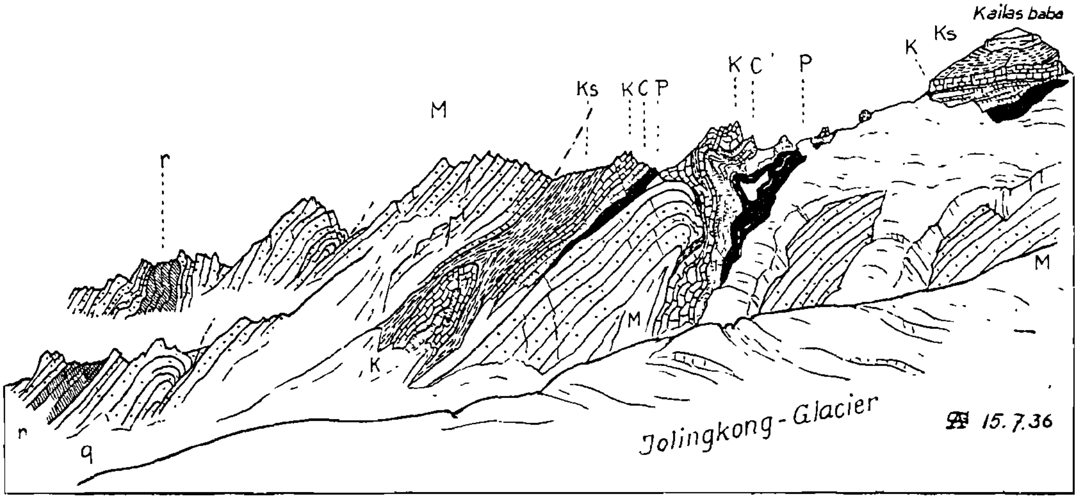


Fig. 98. The northeast side of Lebong Pass, looking towards SE (for explanation see Fig. 101).

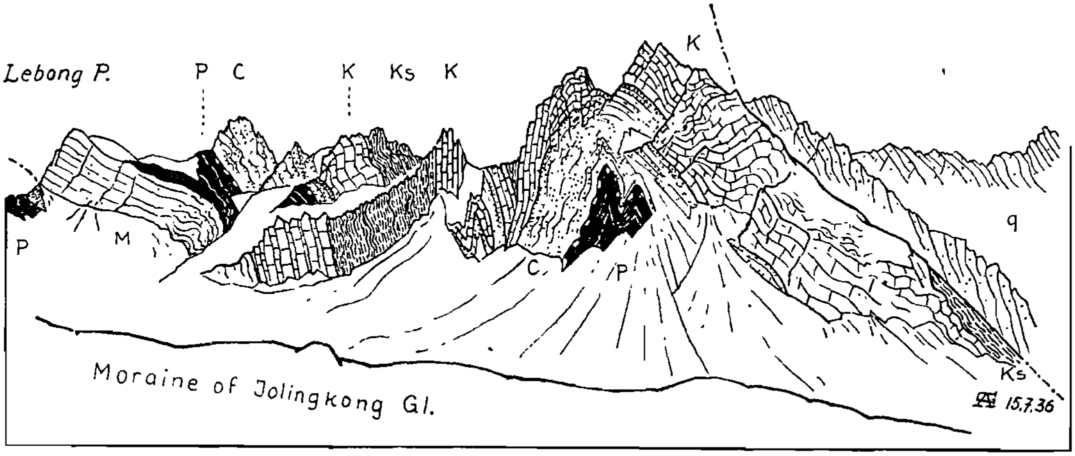


Fig. 99. Northeast side of Lebong Pass, looking towards NW (for explanation see Fig. 101).

The corresponding structure is crossed on the trail, but too close to get a general impression. However, the different horizons recognized on the opposite side of the Joling Kong glacier can be nicely verified (Fig. 99).

The syncline along the trail seems to be rather deep. Indeed, we step for several hundred meters over Kuti shales (Pl. V, Sect. 9a and Fig. 99).

The gap of Lebong Pass (5300 met. barometric) is made of black Productus shales (with clay-iron concretions like those of Spiti shale), cut out below white walls of Muth quartzite which seems to be thrust upon the black shales. The latter dip steeply towards NE. A. GANSSER had the chance to find on the pass itself two beautifully preserved, rare ammonites with suture lines, characteristic of upper Permian. According to Professor JEANNET they are

Cyclolobus Oldhami WAAGEN (Pl. XI), and
Cyclolobus Walkeri DIENER.

On the Lebong pass we are faced with a tectonical problem, which on account of the monsoon fog we could not solve. As mentioned above, the Muth quartzite walls on both sides of the pass are superposed on the Permian shale. On the other hand, it seemed to us that this quartzite continues southeastward to form the core of the Kailas baba fold. A. GANSSER

thought of an envolvment. But this idea was not confirmed when studying the walls on the SW side of Lebong pass over which we had to climb down.

There, on the northern side of the "trail" (which might just do for a chamois), we again find below the Permian shales of the pass the normal Silurian sequence: white Muth-quartzite about 150 meters, and brown dolomite quartzites. The latter, folded in the lower part, are thrust over a black band of Permian shale (Fig. 100).

We are here on the spot which was photographed by GRIESBACH (20, Pl. 20), not to show this thrust, which he does not mention, but to illustrate a sharp fault, which caused the weathering-out of a couloir, and cuts off the whole series forming the walls above. The dip of the fault plane is 35° to SW. It is indicated in our section 9a Pl. V. GRIESBACH's photograph is reproduced in WADIA's Geology of India. It must here be emphazised that this type of fault is an exception in Himalaya structure, rather than a characteristic tectonical feature.

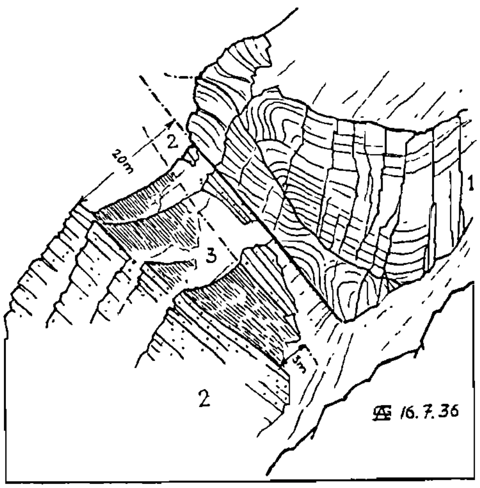


Fig. 100. Detail of the Thrust on the SW side of Lebong Pass, looking towards NW. 1 = brown Muth quartzite; 2 = white upper Muth quartzite; 3 = Kuling shale.

Characteristic are the thrust planes. The above mentioned fault of small displacement cuts at a right angle the Silurian dolomite-quartzite, which is again thrust upon the normal series of black Permian shale. Below it again follows Muth quartzite (100 meters), brown quartzites (700 meters), and variegated lower Silurian limestone and shale in normal succession.

This thrust on the SW side of Lebong pass seems, however, not to be of a primary order. Indeed, we followed the black Permian band along the rocky face above the Lebong glacier, to the place where it joins the narrow syncline at the SW side of Kailas baba. This thrusting movement is thus to be regarded as being of small amplitude. The Kailas baba syncline is figured below.

GRIESBACH (Mem. Pl. XXIII) also published a fine photograph taken from the right moraine of Lebong glacier towards east. The structure, which is not explained on that plate, can be determined by comparison with our Fig. 101 and Pl. IV, Sect. 8. Kailas baba. On GRIESBACH's photograph the summit is in the middle, above the glacier, while the black wall to the right is the shaded Muth quartzite of a normal position. (See also Phot. 139 and 141 in 30).

The normal Muth quartzite series forms a great arch over a zigzag folded anticlinal core of variegated shales and limestones. But the south-western limb is not correspondingly developed. At least on the south side of the lower part of the Lebong glacier, the quartzite is folded and faulted in a way not yet understood. Through fog and clouds, part of the background was visible, showing a normal superposition of southwesterly dipping Permo-Triassic.

Certainly, the glaciated side valley coming from the SE towards the end of Lebong glacier, is a synclinal one. On its south side, we again find the normally rising Triassic to Silurian succession, with the black band of Productus shales dipping 70—80° to NE. (Pl. IV, Sect. 8.) This Triassic sequence, although extensively covered by moraine and talus, again appears above the great camping ground of Bidang 3900 meters on the eastern slope of the Dhauli, called Khumling on the official maps. Close behind it, on the NE side, is an outcrop of red Silurian, which must be thrust over the Permo-Triassic. It is the lowest recognized and probably one of the less important thrusts of the Northern Ranges over Permo-Trias.

We now follow the trail through the transverse gorge on the SE side of the Dhauli Ganga.

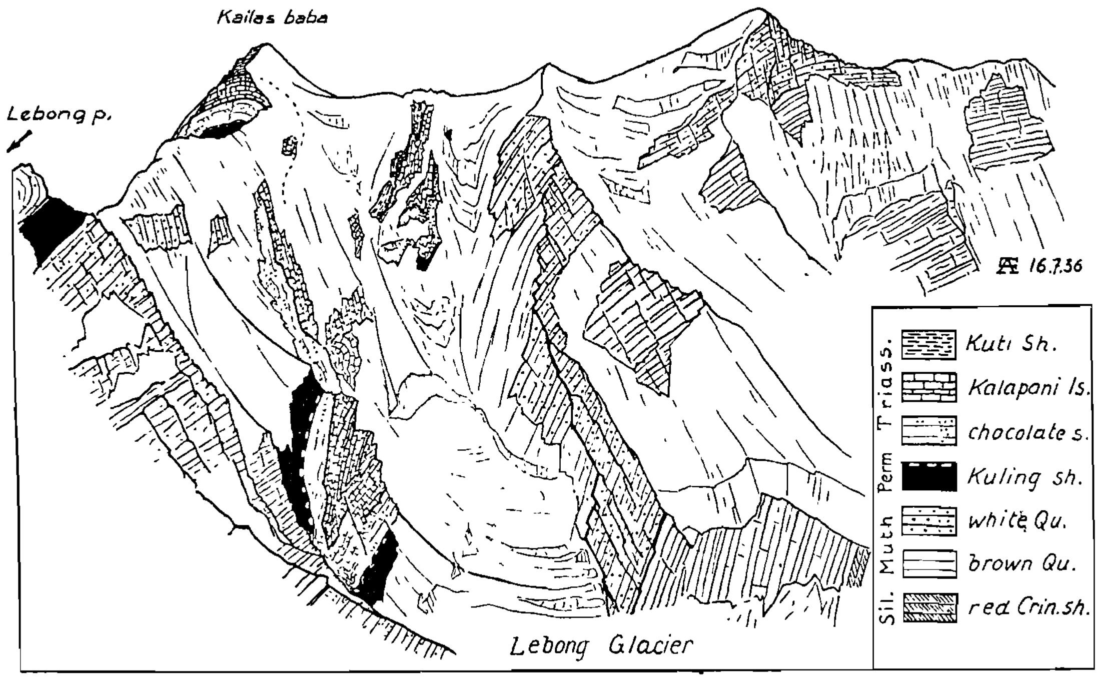


Fig. 101. View of the Kailas baba Syncline above the Lebong Glacier from the crest SE of Lebong Pass.

As far as we could judge during heavy rain, the huge section presents a normal series of sediments, with local folds only, but dipping as a whole regularly towards NNE at angles of 45 to 60°.[1] The following divisions were noted below the Permo-Triassic:

3 Calcphyllitic Garbyang series, about 4500 to 5000 meters, slightly sericitic in the lower part and diagonally crossed by a cleavage of about 80° to NNE.
3 a brown weathered calc—chlorite— phyllite with much greenstone, of Garbyang type, about 2200 meters.
3 b gray phyllites with green layers and some beds of Crinoid limestone, about 1500 meters.
3 c brown weathered calcphyllite, about 1200 meters (upper Garbyang series).
4 a variegated shales, in lower part chiefly greenish, with a layer of brown sandstone, Ordovician. Interruption of outcrop.
4 b red Silurian limestones and shales, 300—400 meters.
5 brown quartzitic series, about 600 meters.
6 Muth quartzite 100 meters (?).

Finally, the base of these Garbyang phyllites is exposed on the SW side of Lissar Valley at the confluence with the Dhauli, formed of gray and greenish quartzite with conglomerate, 600—800 meters. The age of these formations will be discussed later.

b) Glaciation and Morphology

The Joling Kong glacier fills the upper part of the valley on the north side of Kailas baba. The ice tongue is at about 4500 meters and is swimming upon ground moraine. The moraine washed down by the glacier rivers fills the depression behind the block field of Joling Kong (Pl. IV, Sect. 8, and Phot. 137 in 30).

[1] On the geological map of GRIESBACH (20), the boundary of his slates (Haimanta system) and the Lower Silurian, is drawn along the Dhauli Gorge for more than 3 km across the strike. Thus the upper boundary of his Haimantas, east of the Dhauli, is stratigraphically 3—4 km higher.

Much larger is the Lebon glacier, which originates on the west side of Kailas Baba (see Phot. Pl. 19 of GRIESBACH, 20). Fed also by hanging glaciers on the south side, it flows in a curve of about 5 kilometers length down to 4350 meters. At the turn towards north, the ice stream is reduced to a width of about 300 meters. The northern lateral moraine, as usual, is a sharp crest overtopping the grazing ground outside of it for about 30 meters, and even 40—50 meters further west (Fig. 102).

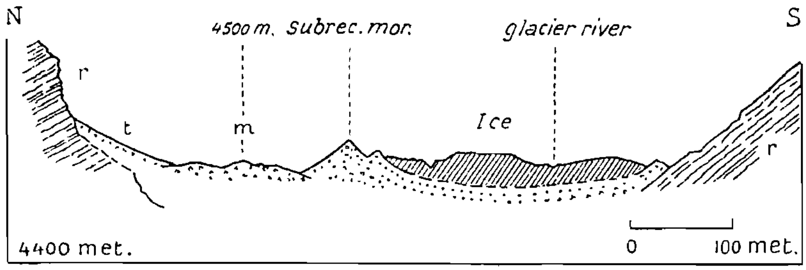


Fig. 102. Transverse Section of Lebong glacier at its northern Knee. r = red Silurian limestone and shale; m = grazing ground on old moraine, partly washed out; t = talus; glacier hatched, swimming on ground moraine.

This high crest of the subrecent moraine again shows the inability of the glacier even in its stronger stage to reach and to polish the rock walls.

The lower end of the Lebong glacier presents an unusual phenomenon. In front of the slightly retreated ice tongue, a lake is formed, of which a part (about 80—150 meters) is not yet filled up. On its edge there is a bubbling well from which are gushing out, under pressure, about 300 litres per second of glacier water (Phot. 35, Pl. XV).

The terminal moraine damming the little lake, has a very steep outward slope over which the glacial river jumps down in a cascade of about 150 meters height. Then follows a normal drop until the glacier river falls down into the Dhauli Gorge. Bidang (or Khumling) encamping ground is a terrace at 3950 meters (barom.), about 100 meters above the Dhauli, overstrewn with erratic blocks, some of which were estimated 1000 cubic meters or more. They probably derive from the Pleistocene Dhauli Glacier.

The trail follows the southeast side of the Dhauli Gorge downward, high above the roaring river. A little less than half way from the Rama glacial side river to the confluence with the Lissar Ganga, the trail rises again over an old moraine barrier of a stage of recession, at about 3600 meters. There, the river in a similar way as on the Kali (Fig. 32), has cut an epigenetic gorge into the calcphyllite of about 150 meters depth (Fig. 103).

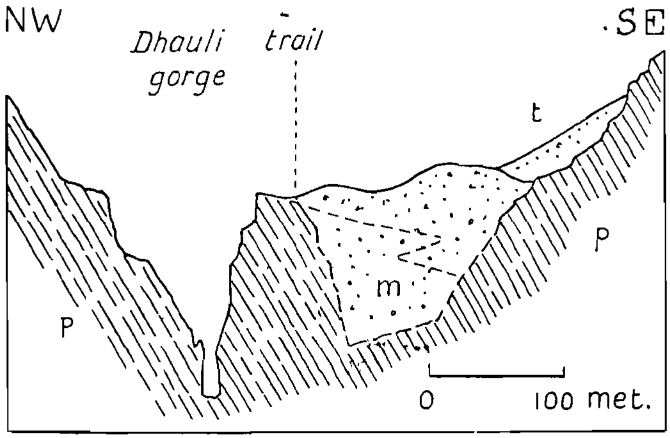


Fig. 103. The Epigenetic Gorge of the Dhauli Ganga, about 2 km NE of its confluence with the Lissar. p = calcphyllite of Garbyang series; m = Pleistocene moraine; t = talus.

The confluence of the Dhauli with the twice to three times larger Lissar is at about 3250 meters. The water of the latter has a greenish tint, probably from the chloritic Garbyang series and the green quartzite at its basis.

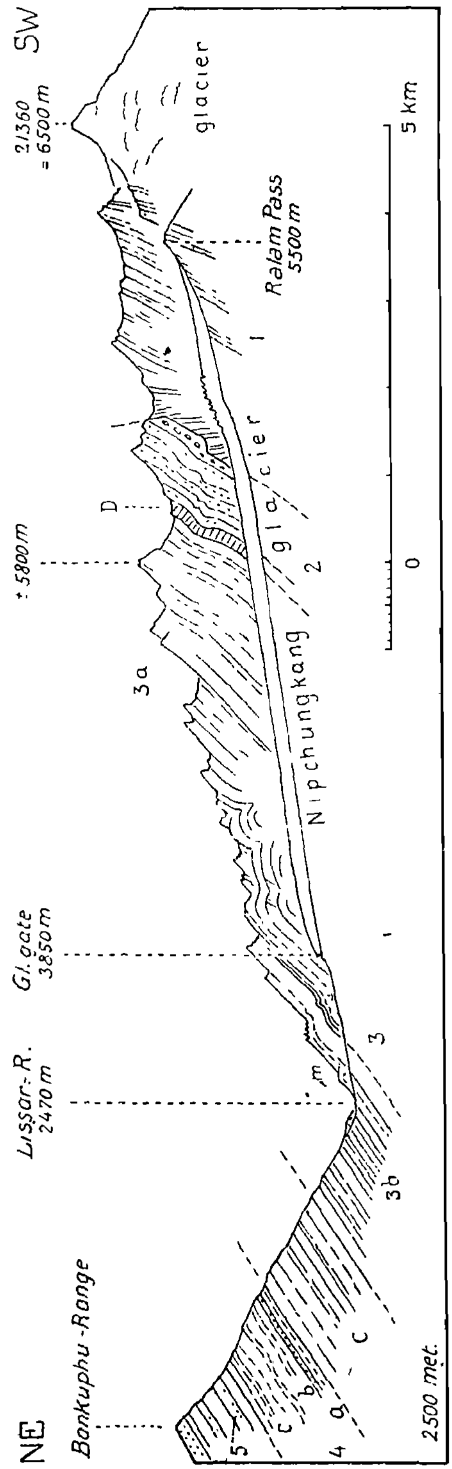


Fig. 104 The Southeast Side of Nipchungkang Glacier

1 = Martoli series, dark calcphyllite and quartzitic sandstone, Algonkian (?); unconformity to 2 = Ralam series, 600—800 meters; a = conglomerate and graywacke sandstone, about 100 meters; b = greenish and reddish quartzite, 600—700 meters; c = rusty yellow dolomite, 70—100 meters D; 3 = Garbyang series, calcphyllite, 4500—5000 meters; a = Calcphyllite, gray and greenish to brown, with chloritic layers in the basal part; about 2500 meters; b = greenish-gray middle series, about 1200 meters; c = brown calcphyllite, about 1000 meters; sharp limit to 4 = variegated shales and limestones with subordinate sandstone, Ordovician to lower Silurian, 1000 meters: a = violet shales, b = green shales, c = red and reddish shales and limestones; 5 = quartzitic Muth series, upper Silurian.

Ralam Pass

a) Tectonics and Stratigraphy

At the junction of the Lissar and the Dhauli Ganga and below it the greenish quartzite forms the walls on both sides of the longitudinal valley with a steep undulating dip towards N 30° E. But apart from Tizang upwards it remains on the southwestern slope of the Lissar, and crosses the Nipchungkang glacier about 6 kilometers SW of this river. There, the continuation of the Dhauli section can be studied downwards to the underlying Martoli series (Fig. 104).

As shown by the above section, also along the Bankuphu Range[1] the formations gradually deviate from the topography in crossing the crest from east to west:

Above Marcha, the red Silurian appears on the top of the SW slope. Thence this variegated formation gradually descends to form the middle part of the slope 7- 8 km more to the NW, while still farther, 25—28 km NW of the Lissar- Dhauli junction, even the black Productus shale and the Triassic series obliquely cross the crest to come on the Lissar side, still at a 45° dip to the NNE, as seen at a long distance.

The most interesting stratigraphic division crossed by the Nipchungkang glacier[2], is Nr. 2 of the above section with its basal conglomerate (Fig. 105). In a black groundmass of argillaceous sandstone are embedded quartz pebbles up to the size of a fist. The sandstone between the more conglomeratic layers is of the type of graywacke. The great mass of sandstone and hard quartzite above is chiefly greenish, but also reddish to violet in the lower part. Also the dolomite on the top is easily

[1] Bankuphu is the name used by GRIESBACH for a summit of the watershed range between Lissar and Dhauli Ganga.

[2] Top. sheet Nr. 254, 1" = 1 mile.

recognized even at a long distance, characterised by its orange-brown weathering. For this quartzitic-dolomitic series the name of Ralam series is proposed.

The conglomerate with a steep northeastern dip rests unconformably upon dark phyllites. However, it is difficult to judge how much of this basal irregularity is stratigraphical and how much of it has been tectonically disturbed.

The phyllitic series below the conglomerate differs little from that of the Garbyang series. It is partly less calcareous and more sandy or quartzitic. On the Ralam Pass 5550 meters, quartzitic calcareous sandstone rocks look out of the snow. They dip 70—80° to E 35° N.

Climbing down over dangerous avalanche-couloirs, and over the great Thercher Glacier which turns towards north, the conglomerate- and quartzite series is crossed again. It forms the gate at the junction of the Thercher- and Kala Baland glaciers, which, after being joined, are known by the name of Shunkalpa glacier. The conglomerate dipping 60° to N 20 E, with quartzite pebbles up to the size of a head, is well exposed on the spur at the north of this united glacier, but the basal contact is not recognizable on account of talus and moraine.

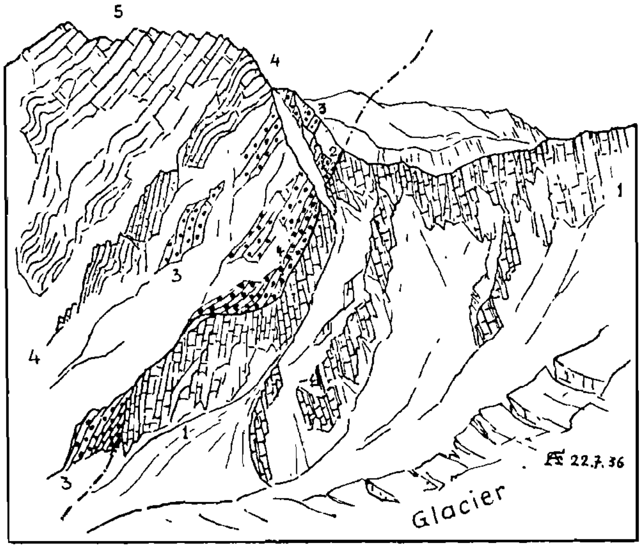


Fig. 105 View of the Contact Martoli-Ralam Series on the NE side of Ralam Pass.
1 = calcareous quartzitic Ralam series; 2–5 = Ralam series; 2 = coarse quartzitic sandstone with quartzite pebbles; 3 = coarse quartzitic conglomerate; 4 = sandy quartzite; 5 = green to reddish dense quartzite.

Descending towards the miserable village of Ralam, then climbing westward over the pass called Natsi or Dutuk Dhura (4600 m), and descending down to the great valley of the Gori Ganga, we remain in the monotonous phyllitic unfossiliferous Martoli formation. It is the oldest and largest non- or only slightly metamorphic series of the Central Himalaya. As a whole it is made of sandy to calcareous phyllite of a facies recalling the much younger schistes lustrés of the Alps, more or less sericitic and frequently containing quartzitic layers. The calcareous parts of the Martoli series resemble much to the Garbyang series. Usually, however, the phyllites are of a darker gray. At the Dutuk Dhura, both phyllites and quartzites abound in well-preserved cubes of pyrite.

As we have shown before (Pl. II, Sect. 5 and Pl. III, Sect. 6 c), this phyllitic series overlies the gneiss of the Gori Valley, and is intensely injected at its basis (below Rilkot) by dykes and veins of aplite and pegmatite. Even above these injections they still show the effect of metamorphism by their biotite-porphyroblasts (Natsi—Sumdu—Rilkot), as already described of Budhi, Rilkot and Pindari glacier.

Attention must again be drawn to the abnormal strike, which, west of Ralam, turns towards W, and locally even to WSW, with an average dip of 20° to the North. This is probably connected with an axial pitch of the whole region towards NW.

The total thickness of the pre-Cambrian phyllitic series in this region, after comparing the different sections (Dutuk Dhura, Gori Ganga, Nanda Kot-Martoli), may be estimated at 5 kilometers.

b) Glaciation and Erosion

Just opposite the mouth of the Dhauli, between the little villages of Dakar and Tijang, is a moraine wall at 3400 meters, i. e. about 100 meters high above Tijang. It derives from the Cholungli side-glacier on the SW-side of the main valley. It is regarded as a last stage of recession, the actual end of the glacier being as low as about 3800 meters.

The last village, Sepu on the SW side of the Lissar, at 3500 meters, is on a terrace 90 meters above the river.

The entrance to the Nipchungkang side valley is a gorge, narrowed by hardened moraine, talus and rugged calcphyllite rocks with numerous caverns (the dwellings of the ghosts). The end of the glacier, at about 3850 meters, has the shape of a steeply descending wedge, with a beautiful gate from which originates a wild greenish-yellow river (Phot. 37, Pl. XV). The subrecent moraine crest is 50 - 70 meters above the ice (Fig. 106).

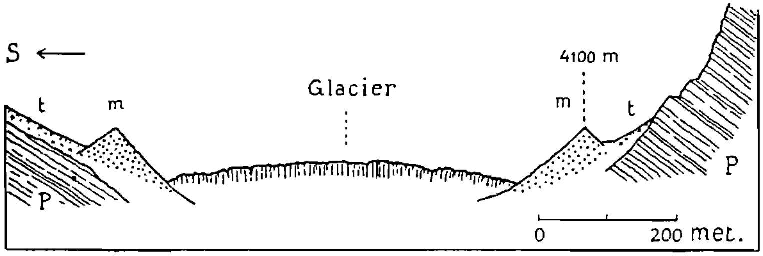


Fig. 106 Transverse Section of the Lower Part of Nipchungkang Glacier.
p = calcphyllite (Garbyang series); m — subrecent moraine; t = talus

There are two collecting glacier basins separated by a spur of Ralam-quartzite. The longer part of the glacier derives from the NE side of point 21360′ (= 6500 meters), and has a length of 9—10 kilometers.

On the NW side of Ralam Pass [1] extend the greatest glacier basins of the Central Himalaya: the Therchег Glacier (8,5 km.) and Kala Baland Glacier (10 km.) They face each other in northern and southeastern direction. The joined ice-stream, called Shunkalpa, flows towards SW for another 4 km.

On Kala Baland, we saw beautiful middle moraines similar to those of an Alpine glacier, but the weather was too bad for closer observations. In any case, these glaciers would deserve a detailed survey.

Just below the junction, the ice is broken up in seracs and fault walls, upon which a most remarkable folding of the ice is visible. As seen on Phot. 36, Pl. XV, the faulted folds lean over to the right (=SE) side, corresponding to the pressure of the stronger confluent (Kala Baland) with its higher surface. A true thrust upon the southeastern part of the glacier coming from the Therchег could, however, not be observed on account of the upper moraine cover.

On the fresh cutting, the dark bands of the ice can hardly be distinguished from the cleaner intervals, which only seem to be somewhat coarser grained and harder, and less adhesive to dust and sand. Probably, the ice stratification represents an annual deposit.

The snout of the Shunkalpa Glacier is at about 3800 meters, squeezed between quartzite rocks of pre-Cambrian age. A good description with photographs is given by Cotter and Brown in 1907 (Lit. 9). It seems that the ice has further retreated since that time. The bare subrecent lateral moraines go beyond the snout for some hundred meters.

The Shunkalpa- or Ralam glacial river and its tributaries have cut fresh V-shaped channels 20—30 meters deep into their own former gravel- and fan deposits which are progressing backwards to the glacier gate (Phot. 22, Pl. XII).

[1] On the topogr. maps 252, 1″ = 1 mile, and 62 B, 1″ = 4 miles, the Ralam Pass is indicated 1½ miles too much north.

Milam and Milam Glacier

Above the great gneiss gorge, above Rilkot (p. 43), and up to Milam, the Gori Valley flattens and widens, and is morphologically as monotonous as is the great mass of pre-Cambrian phyllite, of which it has been cut out. The villages on both sides are situated on old river terraces at 60—100 meters above the present river. (Tola about 3300, river about 3200 meters, Martoli gravel terrace at 3400).

The cleavage of the phyllite still dips 60—70° to NE, whence the pressure came, in spite of the deviation of the stratigraphical dip. At the bridge over the Gori, about half way between Bilju and Milam, the stratification of phyllite including gray and reddish quartzite layers, is steep, and contorted. These are minor structures similar to the greater crustal waves of the Nanda Devi-Milam region (Pl. III, Sect. 6c and coloured plate).

The spur of Milam between the Gori and the Milam glacier river is formed by the high left lateral moraine of the Milam glacier, apparently of a stage of recession after the Würm period. Milam itself, the highest and most important village of the upper Gori Valley, is situated on a level gravel terrace on the west and inner side of the moraine spur, at 11232′ = 3425 meters, and 40 meters above the Milam river. Its only drinking water is a troubled yellowish "glacier milk". The muddy suspension is so fine that it cannot be filtered. The Milam glacier, of a length from SSE to NNW of about 18 kilometers, seems to be the largest one of Kumaon, but is second to the Gangotri Glacier in Tehri State (27 km), on the NW side of the Badrinath group.

The actual end of the Milam glacier is a gate on the right side of the ice tongue at 3500 meters, some 80 meters above the village of Milam, and about 3 kilometers NW of it. On the left side of the gate, the ice front is seen thrusting into the air, and over a huge mass of ground moraine. There, when melting, the blocks from above fall down over the ice front. Should it advance again, the upper moraine would thus be transformed into ground moraine. Like Bhagat Kharak Glacier, the lower 9 kilometers or more, as far as we could advance, are almost entirely, though not very thickly, covered with upper moraine, some local downfalls with or without small crater-like yellow lakes excepted, where dirty ice appears (Phot. 32, Pl. XIV and 33, Pl. XV).

Although the main glacier is fed by several tributaries, no middle moraine is formed. On the contrary, the blocks on the lower two kilometers are ordered concentrically, as seen at a distance by their different shadings: behind a reddish parabolic arch follows a narrow bluish row, then a wider yellowish one. The blue ones probably derive frome the pyritic phyllite, the yellow one from a dolomite seen in a semi-synclinal shape on the western back ground, and the red from the conglomeratic sandstone series below, which seems to be the continuation of the Ralam Pass series. However, we looked in vain for this series on the eastern side of the Milam Glacier.

The official map (sheet 62 B, 1″ = 4 miles), shows five side glaciers from the SW-side, and three glaciers from the NE-side, joining the main valley glacier. Possibly, such conditions partly existed when the first map was surveyed (Sheet 254, 1″ = 1 mile, 1874). Indeed, the subrecent left lateral moraine of the main glacier reaches some hundred meters beyond the glacier gate. But at present the first side glaciers do not reach the main glacier. The Shakram glacier (the first one on the SW-side), has its own glacier gate at about 3900 meters, half a kilometer or so away from the main glacier. The second southwestern side glacier just breaks across the subrecent lateral moraine of the main glacier, without advancing as a separate limb.

The Milam glacier, situated on the shady side of the highest mountains of the Central Himalaya, with its gate at 3500 meters, reaches thus 250—300 meters farther down than any

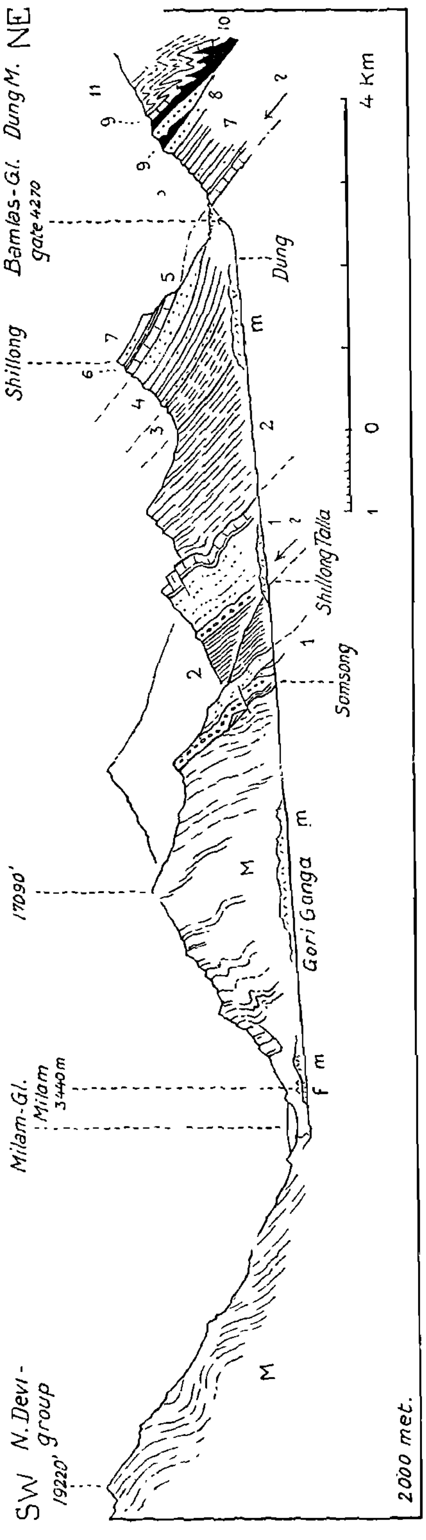


Fig. 107. Section of Milam and uppermost Gori Ganga. M = Martoli phyllite; 1—7 = see text; 8 = Muth quartzite; 9 = Productus shale; 10 = Kalapani limestone; 11 = Kuti shales; m = moraine; f = fluvioglacial terrace.

other glacier which we encountered in the Central Himalaya. It is the counterpart to the Kali Glacier, where only the side glaciers have been preserved.

On the whole, the Milam glacier is an extremely lazy and almost equalized stream, loaded with mud, bedded on a thick body of moraine, and accompanied on both sides by moraine walls. Here, as on most of the other glaciers, we find outstanding subrecent lateral moraines of the main glacier which, at some places, reach a height of 30—40 meters. And here, as on Bhagat Kharak, there are depressions between them and the rock walls, one of which, at Shangas Kund 3950 meters, is filled with an undrained green lake about 80 meters wide and 100—150 meters long.

Cotter and Brown in 1907 (9, p. 153), described the snout of the Milam Glacier, and made a sketch of it. According to them, the eastern lateral moraine goes 700 meters beyond the glacier gate. The reliable old native Kai Kishen Singh Bahadur of Milam stated that this extension was reached in 1830. If so, the high subrecent lateral moraines, which we found on most Himalayan glaciers, correspond roughly to the advance of the Alpine glaciers early in last century, when the Rhone Glacier reached one mile beyond its present snout[1].

The Gori Valley above Milam

a) Tectonics and Stratigraphy

We follow the trail along the Gori Ganga north of Milam, first through a gorge over walls of phyllite, until 3—4 km from Milam we come across patches of violet slates, which support the Ralam Conglomerate of variable thickness, 30—50 meters. The ground mass of violet to red sandstone contains pebbles of white, violet and red quartzite up to more than the size of a head. It seems to pass upwards into quartzitic sandstone with slaty layers, and is overlain by brown weathered calcphyllite with green bands, in the upper part of the Garbyang type. The thickness of the latter was estimated at 500—700 meters. Then follows, below the mouth of the Samgong river, apparently with an irregular basis, thrust upon the Garbyang calcphyllites, a mighty second series (Fig. 107):

[1] The great historical advances of the glaciers in Switzerland were generally in 1620, 1818—1820 and 1850—1855.

1 a) Conglomerate, about 50 meters (Phot. 38, Pl. XVI);
b) red and green sandstone or quartzite, interbedded with shale, and capped by 100 meters of green quartzite, the whole 500—700 meters;
c) brown weathered dolomite, about 50 meters.
2) Calcphyllite, greenish-gray, over 1000 meters = Garbyang series, dipping regularly 45° NE.

The foot of the Shillong peak is now reached. The upper limit of the Garbyang series seems again to be obliterated by talus, while the walls of the Shillong permit the establishment of the following sequence:

3) about 500 meters of greenish to reddish shales (Ordovician?) passing to
4) 500—600 meters of brown quartzite, with white top layer (Muth quartzite). Sharp limit to
5) about 100 meters of gray to greenish, dense, nodulous limestone; sharp limit to
6) about 50 meters of red calcareous shale and greenish shale;
7) brown quartzite forming the top of Shillong peak.

The question is, whether this is a normal series. We rather had the impression that limestone Nr. 5, huge blocks of which have fallen down to the bridge of Dung 13720′ (recalling that of Mangshang pass) forms the basis of a new thrusted series. If so, the gray limestone would be lower Silurian, or Ordovician rather than Devonian.

Just in front of the mossy encamping terrace of Dung rises a magnificently banded mountain forming a spur in the place where the two valleys meet. It recalls the Nabi Peak of Kuti Valley. Bad weather prevented us from acquiring a definite knowledge concerning it. However, we think to have established the following structure:

The southwestern foot of the Dung mountain is the continuation of the top of Shillong, made of gray limestone and variegated shale. The walls above are formed of normally superposed brown quartzites of remarkable thickness, supported by 100—150 meters of white Muth quartzite (Fig. 107).

Climbing from the bridge of Dung northwestward along the northern moraine of the Bamlas Glacier, we come to a sharp corner below point 18263′ of map 62 B, where the peculiar structure of Fig. 108 is seen.

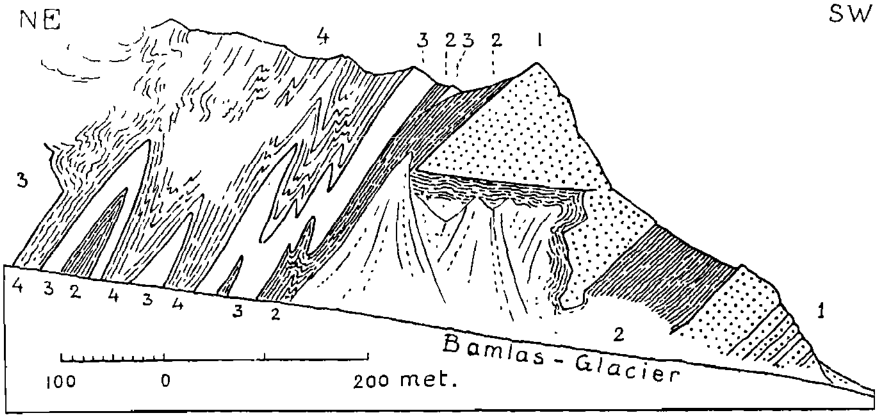


Fig. 108. Detail of the Structure at Bamlas.

1 = white Muth quartzite;
2 = Productus shale;
3 = Kalapani limestone;
4 = Kuti shale.

It seems thus that the normal superposition of the Bamlas series has been intensely disturbed, so that the hard quartzite in its plastic clay bed broke, while the well-bedded Kalapani limestone, normally intercalated in shales, has been intensely folded. The question is, whether we are here at the northwesterly end of the Nihal thrust. Fog and fresh snow fall prevented us from photographing the wonderful exposure of Bamlas.

The Anta Dhura (Utta Dhura) Pass 17590′ = 5375 meters, is in the northwestern continuation of the folded synclinorium described above, and is weathered out of Kuti shales

dipping 70—80° to E 15 N. Their upper part here and also on the Jayanti Pass is characterized by more or less regular bedding of impure limestone layers, each 10 -50 centimeters thick, at distances of 1—3 meters within the dark shale. This facies, at Topidunga, was mapped by GRIESBACH as a faulted block of Carboniferous.

b) Morphology and Glaciation

The upper Gori Valley is pasted with hardened old moraines. They are weathered out in the shape of magnificent "earth pillars", especially where the valley widens as at Jimgong, Samgong and Dung. Above the narrow gorge, 3 km from Milan, the channel is V-shaped in moraine which fills the valley, in places from the bottom up to 150 and nearly 200 meters above the river.

About 2 km south of Dung, we come to a terminal moraine of a last receding stage, at 4200 meters. About 50 meters above it, and 150 meters above the Gori River, is the termination of a living side glacier coming from the SE-side (Bambadhura massive). The dirty ice tongue projects by thrusting over the great mass of older moraine making glacial erosion of the rock bottom impossible.

The encamping ground of Dung is a slightly inclined terrace at 4150—4200 meters modelled out of moraine ground.

Turning from Dung to NW, the trail climbs over the left lateral moraine of the Bamlas Glacier, the source of the Gori River. The glacier gate is at about 4300 meters. Above the steep and crevassed lower part of this glacier is a flat step at about 4600 meters, with a depression behind the side moraine, filled with recent fluvioglacial gravel. At Bamlas, the glaciers from W and NE join, while the Utta Dhura Pass, 5370 meters, is entirely free from ice.

The Region North of Utta Dhura

The Utta Dhura Pass is on the great watershed between the Kali and the Ganges. Nearby, in a northern direction over the Kungribingri-, Kiogar- and Balchdhura Passes, is the even more important watershed between the Himalaya and Tibet.

a) Tectonics

In this region we encounter two new principles of structure:

1 A strike of folds tending from the normal NW towards N;
2 A general pitch of the folds towards north:
3 A general flattening of the folds, which gradually show more upright forms as if they belonged to an autochthonous mountain range of the Jura type.

The effect of items 2 and 3 is to lead us into a region formed not only of the youngest Triassic formations, but even of a mass of Cretacic flysch, crowned with exotic thrust sheets. This flysch, although belonging for the greater part to the normal cover of the Himalayan folds, will be described in the chapter on the exotic blocks.

With the Fig. 109 and Sketch-map 133 at hand, we shall follow the different folds up to the frontier of Garhwal (Kiogad).

The axis of the Utta Dhura synclinorium continues towards NNW at the Kiangur Pass (5250 meters), which is formed of an isoclinal wedge of Spiti shale (Upper Jurassic). Towards SSE, on the south side of the Girthy Gorge, it is squeezed out between the upper Triassic limestone in the shape of a narrow black band (Fig. 109 A and B).

At Chidamu encamping ground, the Kiangur syncline is no more leaning towards WSW, but has become upright and doubled by a minor anticline (Fig. 109 D). The latter suddenly

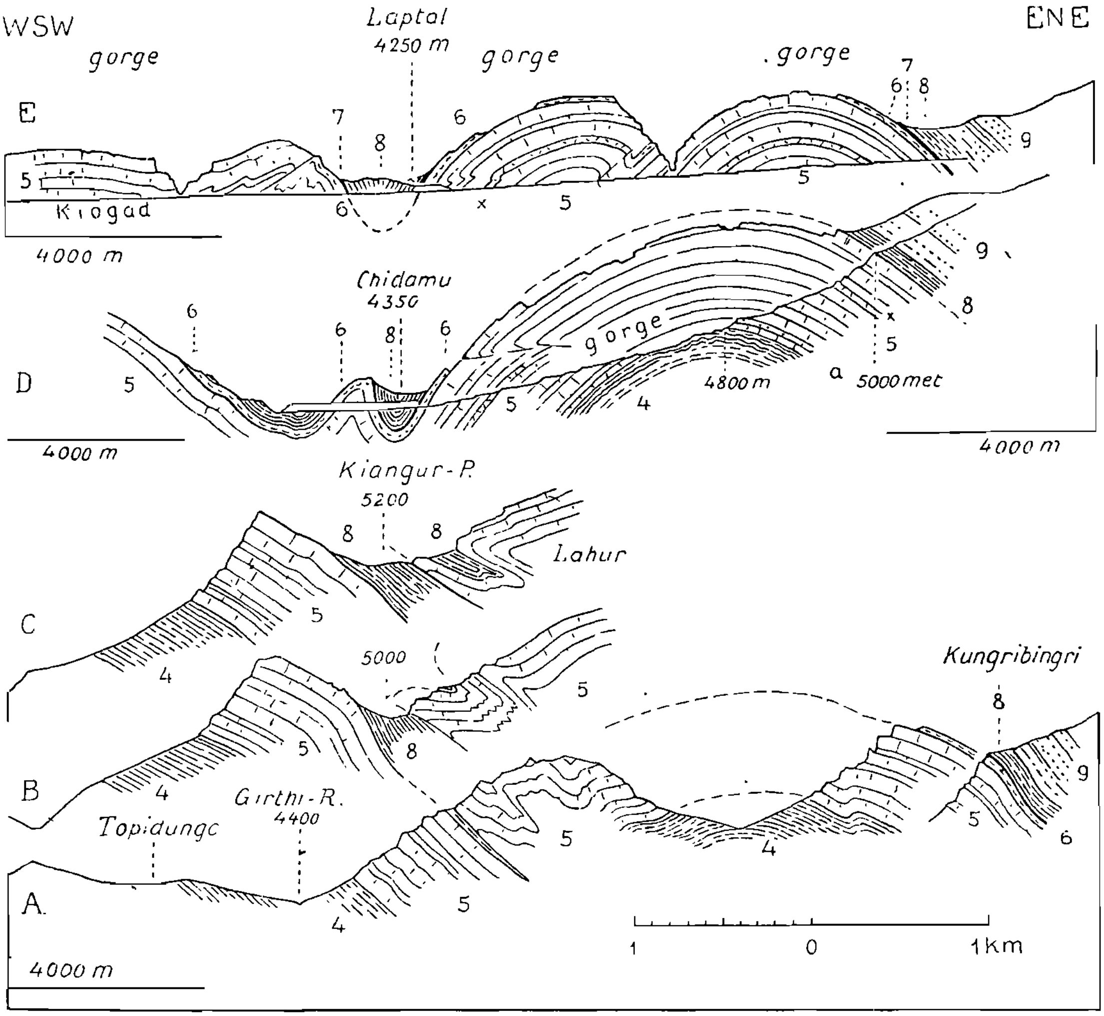


Fig. 109. Sections across the northernmost folds from the Girthy River to the Kio Gad. 4 = Kuti shales; 5 = Kioto limestone; a = basal part with shale and quartzite; x = problematica; 6 = lumachelle, Lias; 7 = ferruginous oolite, Callovian; 8 = Spiti shale; 9 = Giumal sandstone (lower flysch).

appears at the Chidamu river with an axial rise of 35° to NNW. In the same section, the crumpled anticline of the Girthy, which we call the Lahur anticline, has become a beautiful upright arch. It is completely cut across by an imposing gorge east of Chidamu (Fig. 109 D and Phot. 42, Pl. XVII). Thence the axis gradually, though not quite equally, pitches northward at an angle of 8—12°, so that the Triassic, including the Laptal-lumachelle, definitely disappears below the Spiti shales and the flysch on the north side of the Kio Gad. Before disappearing, however, the Lahur anticline has become doubled, as seen in climbing across the wild Kio Gad gorge above Laptal encamping ground (Fig. 109 E).

We have now arrived in the region of "Malla Johar and adjoining parts of Hundes", mapped by A. v. Krafft, and published in his "Notes on the Exotic Blocks" (36, 1902). This most valuable publication describes the flysch and the exotic region, but only touches upon the geology of the underlying and surrounding Himalayan folds.

Before closing this chapter, we have to step backwards to the region of the famous Kungri-

bingri Pass, the most frequented one between Milam and Tibet (18300' on the India maps = nearly 5600 meters, 5500 m according to our barometric reading).

South of the Girthy River, on account of the axial rising towards south and deeper erosion, the core of the Lahur anticline appears at the surface. Indeed, just north of the peak 19350', east of Jayanti Pass, sticking out in shape of a wall above the Nadji Kaong glacier, the Muth quartzite is recognizable, normally covered by about 100 meters of black Productus shales, of Kalapani limestone, and the thick series of Kuti shales. A fault seems to cut off the northeastern limb of this anticlinal core. Coming from the South, it is the last appearance of the Dravidian within the exterior anticlinal ranges along the Tibetan frontier. The marginal anticlines, as seen from Kungribingri Pass, are all lower. Indeed, the three eastern anticlines, situated on the Tibetan side, only show Kioto limestone on the surface, the synclines being filled with Spiti shales, until finally the surface is made of flysch with exotic blocks of the Chirchun area, covering all the supposed continuations of the Himalayan folds underneath. As already mapped by v. KRAFFT, only the outermost anticline continues for some distance north along the Chirchun River.

The Chirchun encamping ground, at 5000 meters, is on the spot where the broad plateau-shaped Chirchun anticline with its lumachelle pitches below the Spiti shales and flysch, complicated by longitudinal and transverse faults. The strike of the folds here is N 15 W on an average, and seems to be due north in the easternmost Himalayan range, (Chanambaniali) mapped by v. KRAFFT. Nothing is known of the region east of Chanambaniali anticline and Chirchun river.

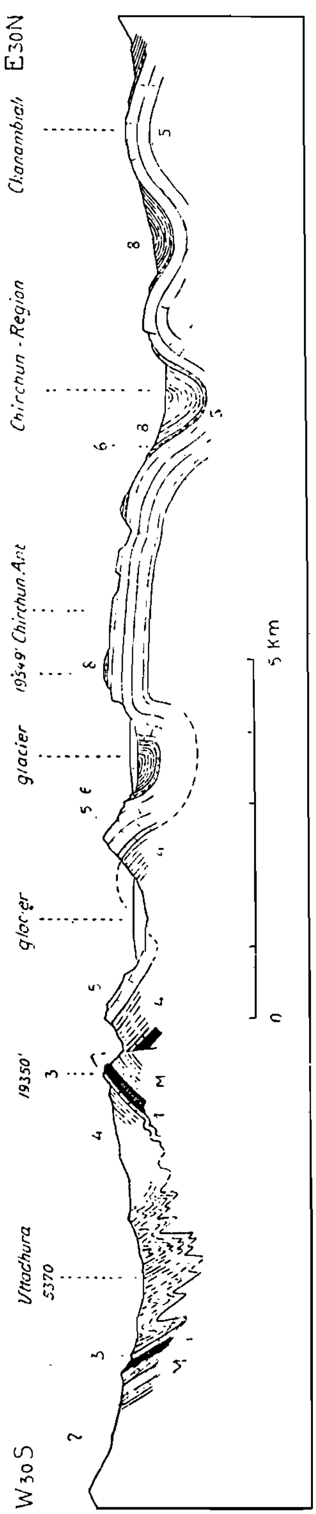


Fig. 110. Approximate Section from Utta Dhura to the Chirchun (= Chitichun) Area.
M = Muth quartzite; 1 = Productus shale; 3 = Kalapani limestone; 4 = Kuti shales; 5 = Kioto limestone incl. basal quartzite; 6 = Laptal formation (lumachelle), Liassic; 8 = Spiti shale.

b) Stratigraphy and Fauna

Compared with the southeastern region of the northern ranges on the Nepal border, a considerable change of facies has taken place towards this northwestern region of Kumaon, which is 80—100 km NW of the Kali.

It is a fact that the Muth quartzite and its cover with well developed Productus shales are still of the same aspect. But at the Utta Dhura, we in vain looked out for the characteristic facies of chocolate shales of the lower Triassic.

Kuti Shales (Norian, 4)

These shales, already 400—500 meters thick in the SE, have even increased. A new facies of their upper part has also developed, characterized by impure layers of limestone.

This subdivision was first encountered on the top of Utta Dhura. At Jayanti Pass, it is so largely developed that it might be called Jayanti formation. But no more ammonites were found.

Kioto Limestone (Rhaetic, 5)

This series greatly increased, from 150—200 meters at Kuti, to about 600—700 meters at the Kio Gad. The complete succession is exposed in the gorge of Chidamu, across the Lahur anticline (Fig. 109 D), where we found the following approximate succession, from below:

1 greenish quartzite forming the anticlinal core,
2 black, more or less micaceous shale, with thin nodular sandy limestone- and quartzitic layers, 10 meters?
3 nodular limestone, 25 meters,
4 repetition of quartzite and limestone, about 100 meters,
  a 10 m white quartzite with sharp boundary to
  b 3 m black limestone;
  c 5 m quartzite;
  d 50—60 m of dense bluish black limestone, followed by 3 m quartzite, 10 m black marly shale, 20 m quartzite;
5 main body of Kioto limestone, well bedded (Phot. 42), 500—600 meters, the upper 100 meters thick-bedded, with ripplemarks near the top (!). Sharp limit on eastern anticlinal limb (discontinuity), to
8 Spiti shale about 100 meters; passage not exposed to
9 Giumal sandstone.

The imposing mass of the Kioto limestone here and in the Kiogad-Gorge above Laptal was found to contain a layer of problematics, which seem to present a suitable guide horizon for subdivision:

About 150 meters (at Laptal 300 meters) below the top of the Kioto limestone, is a massive, light gray, microcrystalline limestone bed of 10 meters thickness, full of white spindles or bands, frequently hollow, of up to 2 centimeters thickness, and 5—40 cm length, irregularly disposed in all directions (Phot. 39, Pl. XVI).

The Kioto limestone, on account of the superposed "iron pisolite" discovered by C. Diener, was considered by Griesbach and others as ranging from Upper Trias to Middle Jurassic. This mistake was caused by overlooking the discontinuity below the "pisolite". We think that C. Diener was right in comparing the Kioto limestone series with the Alpine Dachsteinkalk of the Upper Triassic age only.

Laptal Series (Lias, 6)

Above the horizon of problematica at Chidamu, the following approximate succession was noted at the issue of the gorge (western limb of Lahur anticline):

a dense dark blue limestone (120 - 150 meters), in the upper part a layer with smooth bivalves;
b 15—20 meters of thin-bedded limestone with some bivalves, microbreccia and oolite (facies recalling Alpine Urgonian);
c 10 meters of yellow to reddish spotted dense limestone with layers of lumachelle[1]. Some *Belemnites* and thick shells of Pelecypods. Top layers sandy;
d 45 meters of dense impure limestone, with nodulous and shaly layers, of brown weathering;
e 5 meters of dark marls with limestone layers, sharp limit to
f 8 meters of brown lumachelle with small *Belemnites, Astarte* and *Trigonia;*
g about 15 meters of well-bedded limestone;
h 5 meters of brown limestone with lumachelle, more or less sandy; containing small *Belemnites* and thick shells of Pelecypods: *Cardium, Arca* and other *Arcidae;*
i Spiti shales, contact to
h not exposed here.

[1] Agglomerate of mostly broken sea-shells.

For the brown weathered series with lumachelle c—h, of about 80—90 meters, we propose the name of Laptal series, after the locality 4 km farther north at the issue of the Kiogad Gorge across the pitching Lahur anticline, where they are best exposed (Phot. 43, Pl. XXVII, Fig 109 E and Fig. 111).

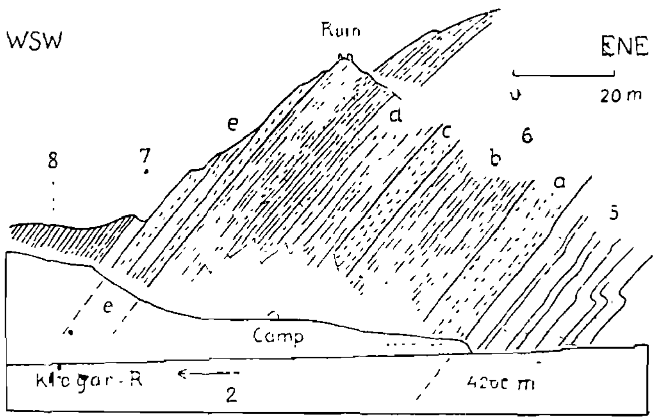


Fig. 111. The Laptal series at Laptal.
5 = Upper Kioto limestone;
6 = Laptal series 65 meters:
a 9 meters limestone of brown weathering, with layers of fine lumachelle;
b 17 meters thin-bedded gray limestone;
c 4,5 meters brown sandy limestone with layers of lumachelle up to $^1/_2$ meter, *Mya, Gryphaea* (?);
d 25 meters gray thin-bedded limestone like b, but with numerous layers of lumachelle of 1—10 centimeters each, chiefly small black oysters, some *Belemnites* and *Pecten*. Upper part with foliated sandy intercalations of 2—10 centimeters each;
e 8 meters of chiefly lumachelle, brown, with small *Belemnites* and oysters.
7 = 3 meters covered, corresponding to the ferruginous oolite;
8 = Spiti shales.

The fossils are not quite decisive for a determination of the age. There is, however, no doubt that the Laptal series must be either upper Rhaetic or Liassic. The presence of *Trigonia* points to Liassic. Although there are some sharp limits between the different horizons of the upper Kioto limestone and the Laptal series, there seems to be no major break within these stratigraphic sequences.

The distribution of the Laptal series is of special interest. It was only found in the region north and northeast of Utta Dhura. Wherever it is lacking, from the Kali to Garhwal, there is a marked though conformable discontinuity in its place. The ripplemarks of the upper beds of Kioto limestone found at Kuti and on the east side of Chidamu gorge, point to an interruption of deposition.

It would seem that the deposition of the lumachelle occurred near a flat shore along the present Lahur anticline. Indeed, on the west side of this fold, the lumachelle series was found at a maximum development (80—90 meters), whereas it is lacking at less than 3 kilometers eastward, as estimated after stretching the anticlinal arch. However, the Laptal lumachelle is again represented at the Kungribingri, 8 km farther SSE on the same eastern limb of Lahur anticline, although at a reduced thickness of 10—20 meters. We also found it on the next eastern Chirchun anticline.

At the northern end of Lahur anticline, the lumachelle goes all around and over the pitching vault at a thickness of 50—70 meters. Also at the lower gorge on the west side of Laptal, along the west limb of Kiangur syncline, the lumachelle is well represented (50 meters).

This Laptal series was already well known to Griesbach. He gave it number 16 on his sections, and called it "earthy shell limestone". As to its age, Griesbach (Mem. 1891, p. 74) says: "the fossil remains which I have found, are too much indistinct to allow close comparison, but Stoliczka was fortunate enough to find several good Alpine Liassic forms in this horizon which is widely distributed over the Central Himalayas". Griesbach found the shell limestone also on the Shalshal Cliff in Garhwal north of the Kiogad, on the top of the Bambanag Heights and on the north side of Girthy Valley, 10 km WNW of Kiangur Pass, from where he made the fine photo of his Pl. 10 (20).

Ferruginous Oolite (Callovian, 7)

We have already described the little discovery at the Chaga Pass, east of Kuti (p. 115). Exactly the same layer of ferruginous oolite was found again on the top of the Laptal series at Laptal and its surroundings.

The "red iron pisolite" was discovered by C. Diener (10, 1895) at the Shalshal Cliff (about 12 km NW of Laptal, in Painkhanda) and at the Chanambaniali peaks SE of Chirchun in Hundes, where he collected a few brachiopods and numerous *Belemnites* (B. *sulcacutus* F. Suess) regarded by F. Suess as being probably Kelloway.

Griesbach's view (l. c. p. 75) has, therefore, to be modified: "Apparently the Spiti shales rest perfectly conformably on the beds with Liassic fossils, and the only evidence of a break in the continuity of the formations is the complete and absolute change of lithological character, as one passes from the earthy limestone of the Lias to the dark crumbling Spiti shales."

Few completely uncovered outcrops are found at the contact. The best one is on the S side of the Kiogad, 1 km south of Laptal encamping ground, (Fig. 109 E and Fig. 112).

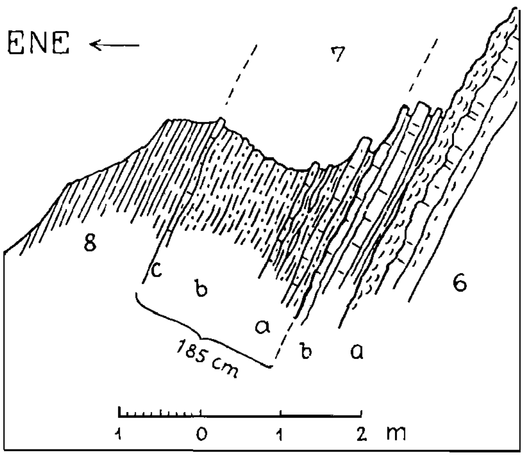


Fig. 112. The Ferruginous Oolite South of Laptal.
6 a Laptal limestone of brown weathering, with lumachelle,
6 b 60 centimeters of dark dense limestone with shaly layers and small *Belemnites*. Sharp limit to
7 185 centimeters of ferruginous oolite;
a 60 centimeters black shale with flat oolitic grains, interbedded with layers of dense limestone containing round, gray ferruginous ovoids. In the top layers *Belemnites* and large *Ammonites (Reineckeites)*
b 125 centimeters of black shales with flat ferruginous ovoid grains,
c 4—6 centimeters of dense limestone with ferruginous ovoids;
8 Spiti shales, black, brittle, with rusty cracks, 35 meters exposed with very few concretions.

The black shales 7 b can hardly be distinguished from the basal Spiti shales, except in looking at them with the lens, which at once reveals the black ferruginous grains, which, one millimeter higher, are absent. This exterior similarity of shales and the scarcity of exposures may be the reason that this stratigraphical key had been overlooked.

The next good exposure is about 2,5 kilometers farther NE in a natural ditch near the end of the pitching Lahur anticline, at Sangcha Talla. The succession, from above, is as follows:

8 Spiti shale. Sharp discontinuity to
7 2 meters or more of ferruginous oolite like that of Laptal,
a dense limestone layers crowded with *Belemnites* of different species,
b chiefly black shale. Sharp discontinuity
6 Laptal series, lumachelle.

Here, the upper and lower boundaries only become visible after working out fresh cuttings with the ice-axe. The oolitic limestone even sticks on its basis in such a way that samples could be gathered for a microscopic research of the discontinuity!

A third outcrop was found at he eastern (upper) issue of the Kiogad Gorge on the eastern limb of Lahur anticline, where the ferruginous oolite is 1,5 meters thick.

Chaga Pass at Kuti is the only place encountered, where the iron oolite is developed while the lumachelle is absent. On the other hand, the oolite is not always present together

with the lumachelle. Thus, at the Kungribingri, the iron oolite layer is wanting between the Laptal-lumachelle and the Spiti shale. In its place, the surface of the Laptal series is impregnated with red clay (Fig. 113).

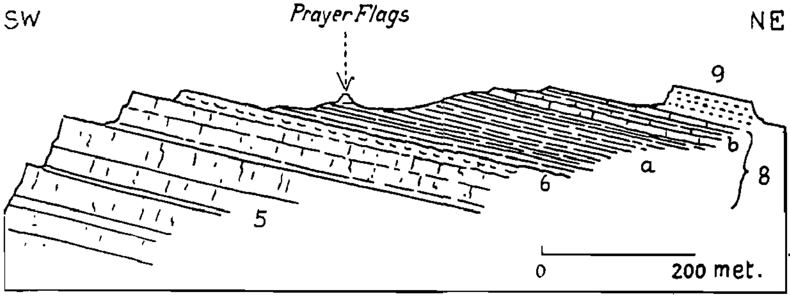


Fig. 113. The Jurassic of Kungribingri.
5 = Kioto limestone; 6 = Laptal series, lumachelle; 8 = Spiti shale, a black shale, b black shale with thin limestone layers; 9 = siliceous shale and sandstone, lower Cretaceous.

Under the microscope, the ovoids are seen embedded in a partly dense, partly recrystallized calcareous groundmass. They average about 1 mm, and are made of calcite with varying content of iron (limonite or goethite) changing their colour from clear white to gray, yellow and dark brown. Even within one grain the colour may alter from one concentric shell to the other. Frequently an angular fragment (shell, quartz or iron ore) forms the core. (These ovoids are thus mineralogically different from the chamosite ovoids in the Helvetic iron Oolite of the Callovian).

FAUNA

The following species were collected from the ferruginous limestone in situ, at Laptal (det. A. JEANNET):

? *Belemnites (Belemnopsis) calloviensis* OPPEL
Macrocephalites cf. *triangularis* SPATH (Lower Callovian)
Macrocephalites (Dolikephalites) cf. *flexuosus* SPATH (Lower Callovian of New Guinea)
Reineckeites aff. *Waageni* TILL. (*Anceps* zone)
Reineckeites Douvillei STEINMANN (*Anceps* zone)
Bonarellia cf. *bicostata* STAHL (Athleta zone)
Rhynchonella and ind. bivalves.

These are all Callovian species. The lower and the upper zones seem to be present, confirming our view of a condensed deposit.

The Spiti shales, after the paleontologic monograph of V. UHLIG, are on the boundary of Jurassic and Cretacic, their lower part being upper Jurassic, Portlandian. It we further accept the discoveries and determinations of STOLICZKA (1865) regarding the lumachelle, we come to the conclusion that

1. the lower discontinuity of the ferruginous oolite corresponds to the interval between Liassic and Callovian. The whole lower Dogger, and probably also the upper Liassic, are missing;

2. the upper discontinuity corresponds to the interval between Callovian and Portlandian. The lower Malm from Oxfordian to Kimmeridgian is absent (Fig. 114).

Thus, the still prevailing conception (8, 1934, p. 308) that the Kioto limestone ranges up to the middle Jurassic, is to be abandoned. This error resulted from overlooking the discontinuity below the oolite.

The similarities of age and facies with the ferruginous Oolite of the Helvetic Alps is striking[1]. In both cases the oolite, although of a fe meters thickness only, and lacking in

[1] See ARNOLD HEIM, Monographie d. Churfirsten etc., Beit age zur geol. Karte der Schweiz, Vol. XX, pt. 3, 1916, and ARNOLD HEIM, in ALBERT HEIM, Geologie der Schweiz, pt. IIIa, 1919, p. 279–286.

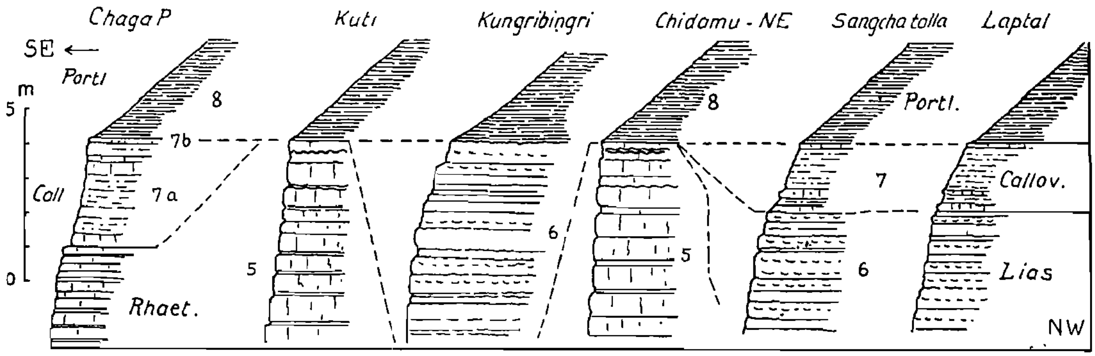


Fig. 114. Details of the Triassic — Jurassic Boundary.
5 = Upper Kioto limestone; 6 = Laptal series with lumachelle; 7 = ferruginous oolite, Callovian; 8 = lower Spiti shale.

places, is widely distributed and characterized by its discontinuities of perfect conformity between the older and younger sediments. And in both cases, the oolite as well as its overlying Jurassic sediments are regarded as deep sea deposits. No signs have been found which would compel one to admit an interval of land erosion. The ochre-like loam in place of the oolite (Chaga Pass, Kungribingri) is explained by "submarine weathering" for which the term exesion was proposed[1]. Such submarine desintegration has recently been found by the Russian hydrologists (M. Klenowa) to prevail at present over the greater part of the Arctic ocean.

Thus, the deposition of the Spiti Shales occured after a phase of submarine sedimentary omission, without transmersion over a land surface. The surface of the Kioto limestone and the Laptal lumachelle below the Callovian oolite, however, may be partly due to slight emersion over a flat strand, where the shell agglomerates naturally came to an end.

Spiti Shales (Portlandian, 8)

"Probably the widest known amongst the Himalayan formations are the beds out of which the numerous and well-preserved Jurassic fossils have been collected, not only by geologists and European travellers, but by natives both of Tibet and India. From ancient times a trade in Jurassic Ammonites has existed; great quantities of these fossils are brought every year to India, chiefly to the holy places of Hindu pilgrimage, and sold as relics to Hindu worshippers" (Griesbach, 20, p. 75).

But notwithstanding this and the fine works of the geologists of the Geological Survey of India since the middle of last century, and of V. Uhlig's paleontological monograph, little is known of the normal stratigraphic and paleontologic sequence upwards, and much time would be necessary to first find the suitable localities. Indeed, at most places, continuous outcrops are lacking, and the soil covered with talus is slipping (solifluction). Besides this, the fossils are collected from concretions which have been washed down to the ravines and brooks, so that they do not permit to distinguish different stratigraphical subdivisions. Possibly, if not probably, there is no mixture of upper Jurassic and lowermost Cretacic fossils, as was the result with the paleontologic collections.

The following observations, however, may be worth mentioning:

The only place we met showing a complete and undisturbed, though not perfect section, is Kungribingri Pass (Fig. 113). There, an upper subdivision of the Spiti shales with flaggy limestone would be worth special attention. It may belong to the Berriasian. Already Diener,

[1] Arnold Heim, Ueber submarine Denudation und chemische Sedimente, Geol. Rundschau Bd. XV, 1924.

1898, has pointed out the upward passage of the Spiti Shales at Kungribingri and attributed the Giumal sandstone to the lower Cretaceous.

At the steep ravine W of Sangcha Talla (map of v. KRAFFT), an uninterrupted exposure from typical Spiti shale up towards Giumal sandstone, was found, which confirms the former view. A gradual passage leads up from

a Upper black Spiti shales, with fine grained calcareous sandstone layers of 2—30 centimeters each at intervals of 1—3 meters,
b 30—40 meters of somewhat micaceous and harder shales with layers and lenses of slightly micaceous sandstone of 5—15 cm each,
c gray, fine-grained, sandy and marly limestone,
d greenish, glauconitic Giumal sandstone.

The thickness of the Spiti shales varies greatly on account of stratigraphic irregularities and tectonic compression or accumulation. Besides this, the vast slope north of Laptal, mapped by v. KRAFFT as Spiti shale, is partly made of Giumal sandstone which may be infolded and partly has fallen down from the walls, the whole slope creeping downward (solifluction). If we regard a—b as Spiti shale, and c—d as lower flysch, we can say that the normal thickness of the Spiti shale along the eastern limb of Lahur anticline from the Kiogad to Kungribingri, averages 80—100 meters.

The list of fossils of the Spiti shales is found in the conclusive chapter.

Morphological Features and Glaciation

North of the Kali-Ganges watershed of Utta Dhura, the surface features change according to the general pitch of the folds. The mountains become less rugged; their heights decrease, and the slopes are more covered with talus, while the amount of morainic material decreases. The passes (Utta Dhura 5370 m, Jayanti 5550 m, Kiangur 5200 m) are gentle and made of Kuti- and Spiti shales. No actual glacier seems to descend below 4800 meters. The glacier NW of Utta Dhura comes down near to Lauka camping ground, ending at about 4900 meters.

Nadji Kaong was called by a native of Milam the glacier N of point 19350' flowing northward and filling the uppermost Girthy Valley. It has a length of about 4 kilometers, and fills the valley cut out into the Lahur anticline underneath the Kioto limestone.

Two greater unnamed glaciers east of it also flow northwards, joining at their lower end, about 4 km NW of Chirchun. Their termination is at about 5100 meters, and they do not conceal their Tibetan aspect, being smoother and cleaner than the Himalayan neighbours (Phot. 170 in 30).

A prominent morphological feature is the Lahur anticline. It is cut across by the Girthy glacial river, the Chidamu and the Kiogad at intervals of 4—7 kilometers, but the intermediate regions still show the uneroded tectonic surface in the shape of a gently pitching vault, while north of the Kiogad the landscape has changed entirely. It is the Spiti shale and the flysch which dominate the landscape, forming vast creeping slopes with rugged sandstone rocks above (Phot. 40, Pl. XVI).

THE EXOTIC KIOGAR REGION

Introduction

We now come to the most problematic region of the whole Himalaya. Although we think to have cleared up several questions of importance, others still remain obscured.

Already in 1892, GRIESBACH (Rec. geol. Survey India Vol. XXVI) and DIENER discovered exotic blocks and "Klippen" on the Tibetan border near the boundary of Almora- and Garhwal districts. The main peaks along this boundary above the Kiogad or Kiogar River were called the Kiogars (v. KRAFFT 1902), and designed as Kiogar Nr. 1—6. When GRIESBACH already in 1879 visited the region first, he considered the Kiogar limestones to be of upper Cretaceous age on account of their superposition on the flysch.

The most important publications on this region are those of C. DIENER (12) on the Geological Structure of the Chitichun region 1898, and A. v. KRAFFT (36), "Notes on the "Exotic Blocks" 1902.

DIENER already was aware that it is the "Klippen" or crags "in their occurrence amidst much younger sediments, and without apparent stratigraphical connection with the latter which makes the structure of the Chitichun area one of the most intricate and most remarkable in the Central Himalayas." Although not illustrating his description, he already compared these occurrences with the Alpine "Klippen", the "lambeaux de recouvrement" of the Chablais and Switzerland "which offer some very remarkable analogies with our Tibetan limestone crags".

Four years later, v. KRAFFT, after new and much more detailed information, based on a six weeks field work, has published his "Notes", accompanied by a geological map 1" to 1 mile, numerous excellent designs (of which his panorama pl. 3 of the Kiogars is a masterpiece) and photographs. Reviewing his observations, he says in contradiction to DIENER (p. 183): "that the exotic blocks of Johar and Chirchun have nothing whatever to do with the "Klippen of Europe", explaining them as the result of huge Tertiary volcanic explosions in Tibet. He added, however, to be "well aware that no completely satisfactory solution of this problem has yet been obtained. Not only are the sources of discharge of the volcanics unknown, but also the facies of the exotic limestone blocks is still a mystery, which is far from being satisfactorily cleared up, and there are several other questions of no small importance, which require further research in the field". (v. KRAFFT, l. c. p. 183).

Indeed, the only way to proceed to a definite solution would have to be based on a new photogrammetric and geologic survey at a scale of 1:25,000 or larger, of the whole Kiogar- and Chirchun areas.

v. KRAFFT's peculiar conclusions are partly based on the following errors:

1 His so-called "tuffs" are mainly siliceous strata with radiolarians,
2 the exotic rocks of the Kiogars are not simple blocks, but part of a folded sedimentary series of vast extension,
3 the latter are less broken up by igneous intrusions, part of the "basic igneous rocks" of v. KRAFFT being folded Jurassic sediments of similar weathering coulour, while some of his dykes are only couloirs appearing black from wetness.

In spite of v. KRAFFT's conclusions, based on an incomplete knowledge of the Alps at the dawn of our modern conceptions of thrusting, E. SUESS in his "Face of the Earth" [1] strongly influenced by DIENER, interpreted the exotic blocks as belonging to a great thrust sheet, the greenstones being injected along thrust planes during the horizontal movement.

F. KOSSMAT (35, 1936, p. 288) supposes that the exotic facies is connected with the zone of Leh in the NW.

Recently E. B. BAILEY (6, p. 1722) in reproducing two designs of v. KRAFFT, draws special attention again to the associations of basic igneous rocks (ophiolites, greenstones) with abyssal formations like radiolarite, in basing his ideas on the far-sighted views developed by G. STEINMANN 30 years before [2]. Although having no positive data of Himalayan deep sea deposits at hand, Professor BAILEY's ideas have proved to be of considerable bearing and he will be amazed that we have found indeed in great extension the radiolarites he probably has thought of, in connection with the igneous greenstones.

Stratigraphy of the Flysch

As already stated by v. KRAFFT, the best stratigraphic sequence is found at Sangcha in the northern part of the Kiogar region. However, even there, the tectonic disturbances do not permit to establish accurately the normal thicknesses of the flysch horizons.

v. KRAFFT distinguished the following divisions, from below:

1 Giumal sandstone 400—500 feet,
2 Upper Flysch 800—1000 feet, with the following subdivisions:
  a red and greenish shales and red shaly limestone, app. 100′,
  b black crumbling shales app. 200—300′,
  c brown weathering sandstones alternating with shales app. 10′,
  d hard black siliceous shales, passing through crumbling shales into e, app. 30—40′,
  e greenish and gray sandstones, alternating with shales passing into f, app. 300′,
  f green (150′) and red (50′) tuffs. app. 200′.

In some points, our observations differ considerably, as shown below:

1. Giumal sandstone (Lower Cretaceous)

The basal part of this formation, which gradually develops from the Spiti shale, is poorly exposed, and chiefly made of shales with more or less calcareous sandstone layers, containing glauconite grains, while the upper part forms fantastic rocks in the shape of blocks and peaks, especially north of Laptal. Much time and climbing would be needed to establish thoroughly the sequence. The following estimates are taken from Sangcha Talla and the folded walls below the SW crest of Kiogar Nr. 3:

a 50—150 met. of shale with glauconitic sandstone layers,
b. 80—100 met. lower glauconitic sandstone, thick-bedded,
c 200 met. of greenish, in the lower part also reddish to black shale, with sandstone layers,
d 150—250 met. of upper Giumal sandstone. It is massive, siliceous, greenish, with a shaly band of 30 met. below the middle.

The total thickness of the Giumal sandstone thus is estimated as 500—700 meters, which means 5—6 times that of v. KRAFFT's estimate.

The upper part of the series c—d forms huge anticlinal walls on the north side of the Kiogar river SW of Kiogar Nr. 3, up to nearly 5000 meters elevation (Phot. 2, Pl. I). The imposing black rocks

[1] E. SUESS, German edition vol. 3, part 2, 1909, pp. 644—649, 675; (English edition vol. 4, pp. 581—567, 586)
[2] G. STEINMANN, Geol. Beobachtungen in d. Alpen, II. Die Schardtsche Ueberfaltungstheorie und die geol. Bedeutung der Tiefseeabsätze und der ophiolithischen Massengesteine. Ber. Naturforsch. Ges. Freiburg, vol. 16, 1905, und "Die ophiolithischen Zonen in d. mediterranen Kettengebirgen". Congr. Géol. Intern., Madrid 1926, C. R. vol. 2, 1927 p. 637

and peaks west of Sangcha Malla are formed of the upper Giumal sandstone d (Phot. 40, Pl. XVI).

Folding and faulting, the absence of a suitable map, and the lack of fossils makes it almost impossible to ascertain whether the above sequence originally was regularly deposited.

The age of the Giumal sandstone is determined by numerous bivalves and some ammonites, found in the region of Spiti, and described by A. SPITZ (57, 1914). It is undoubtedly lower Cretaceous, as generally admitted. The basal part (a) represents the Valanginian, while the top (d) according to the occurrence of *Parahoplites* cf. *Nolani* and *Stoliczkaia* cf. *dispar*, may be regarded as Gault.

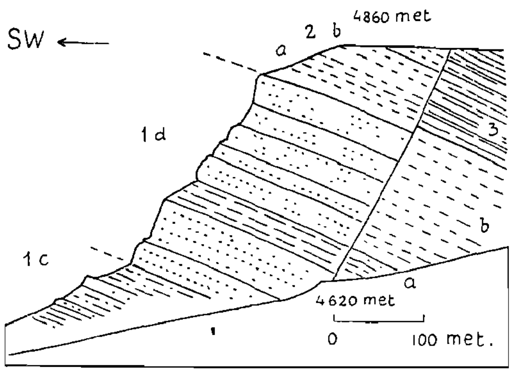


Fig. 115. The faulted Contact of Upper Giumal Sandstone and the variegated shales at Sangcha Malla.
1 = Giumal sandstone, low. Cret.;
2 = green and red shale, upper flysch;
3 = black slates (exposed on opposite side of valley).

2. Upper Flysch (Upper Cretaceous)

Overlying the Giumal sandstone, at Sangcha Malla, we have found:

- a about 50 meters of greenish shale with sandstone layers, passing into
- b about 100 meters of red purple marly shale, and marly dense limestone folded in zigzag. Few Foraminifera (Globigerinidae and Rotalidae). Sharp limit to
- c 500—600 meters of predominently black shales or slates, with occasional clay-ironstone layers, and limestone flags with fucoids, in the upper part also brown sandstone beds, gradually passing to
- d 300 - 400 meters of green and red siliceous sandstones and dense radiolarian hornstones, alternating with siliceous shales. They are overlain by thrusted basic igneous rocks. (Fig. 116).

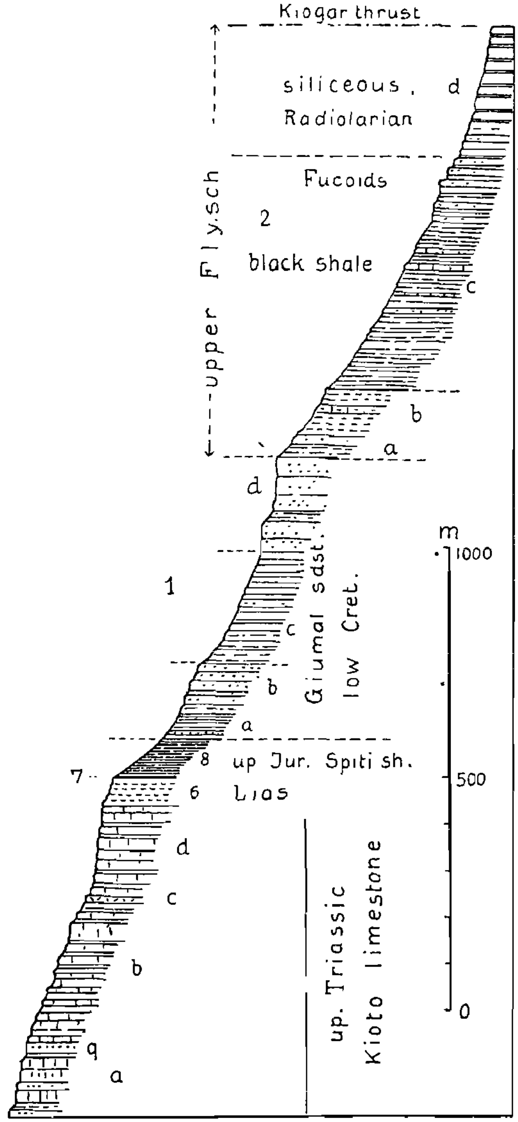


Fig. 116. Generalized Stratigraphic Section of the Himalayan facies in the Kiogar Region. Thicknesses approximate.

Triassic-Jura: 5a = Limestone with quartzite and shale (Chidamu Gorge); c = bed of problematics; 6 = Laptal series, lumachelle; 7 = ferruginous oolite, Callovian; 8 = Spiti shales, upper Jurassic;
Cretaceous: 1 = Giumal sandstone, subdivision see text p. 46.; 2 = Upper flysch, see text above.

The thicknesses of these subdivisions are very variable on account of folding and thrusting. The upper flysch 2a—d was considered by v. KRAFFT as 1000', but reaches in our estimate that many meters, the local accumulations by thrust-folding discounted.

The subdivision a—b, on the Kiogar river, is only 50—70 meters thick. V. KRAFFT mentions bands of red hornstone in 2b.

At Sangcha Malla, it seemed that the Giumal sandstone passes into the upper flysch 2a. There is, however, a sharp limit between the red marls 2b, and the overlying black shales 2c, as verified by digging with the ice-axe.

The black flysch series 2c at some places also contains greenish and reddish shales. The fucoids of the limestone flags (*Chondrites intricatus* BRONG.) are the same as those of the ultrahelvetic Flysch of the northern Alps which now is also regarded as upper Cretaceous.

The brown, somewhat micaceous sandstones are not an individual subdivision, since such layers appear at different intervals in the passage zone of c to d.

At a distance, the black flysch strikingly resembles the Spiti- and Kuti shales, especially by its concretionary layers of siliceous clay-ironstone, which weather with a blue desert varnish. This flysch, however, is devoid of round concretions with ammonites, and is rather harder than the Spiti shales.

The greatest difference of our interpretation with v. KRAFFT's description is related to subdivision 2 d, which corresponds with 4 e – f of v. KRAFFT, the lower one having been called "greenish sandstone with thin brown shaly layers", the upper one called tuff. The latter, between Sangcha Malla and the Balchdhura crest, is a red and green alternation of chert, of conchoidal fracture, with thinner cherty or shaly layers, and is rich of radiolarians. In no place did we find true tuff belonging to the flysch series. We thus regard the top series of the flysch at Balchdhura as a coldwater deep sea deposit.

A microscopic slice Nr. 248 of the green conchoidal chert of Balchdhura shows an isotropic opalescent groundmass without volcanic material. Besides the numerous small globular Radiolarians (Spumellarians), there are also Nasellarians. The shells, however, are partly replaced and filled with a bluish green variety of glauconite.

This uppermost flysch horizon pinches out towards S or SE at the middle Kiogars. On the crest SW of Kiogar Nr. 3, the basic igneous rests directly upon the black flysch with its flags of sandstone and limestone. The siliceous shale, however, reappears in the ravine between Kiogar Nrs. 3 and 4, where it is directly thrust by the basic igneous complex (Fig. 118, 125, 127).

In the southern region of Chirchun Pass (Phot. 48, Pl. XVIII) the black flysch is of great thickness and extension. It is overlain on Chaldu Pass (17 440') by a mighty greenish siliceous series with sandstone, corresponding either to the hornstone subdivision of Balchdhura, or being thrusted upper Giumal sandstone. Farther southeast, surrounding Chirchun Nr. 1 hill 17 740', the flysch is chiefly a shaly radiolarian chert of varying colour from black to red and green. The microscope reveals an amorphous opalescent ground mass, devoid of quartz sand, while the globular radiolarians are filled partly with brown opaque ferruginous silica, partly with fibrous chalcedony. The shells are mostly decomposed. The general solifluction in the Chirchun area does not permit to establish structural details or stratigraphical subdivisions (Phot. 49, Pl. XVIII).

The greenish sandstone of the upper flysch of Kiogar-Chaldu Pass (or possibly thrusted Giumal sandstone) also presents an interesting microscopic aspect. Two slices (Nr. 252) of a specimen therefrom show a fine-grained cherty glauconite sandstone with an amorphous to cryptocrystalline brown groundmass of silica (opal and chalcedony 60%), in which are embedded angular quartz grains of 0,1—0,2 mm (30 %) and grains of glauconite (5 %), detritic grains of feldspar (albite, orthoclase?, microcline, myrmekitic plagioclase), and sporadic grains

of pyrite, magnetite and muscovite. Besides the ordinary blue-green cryptocrystalline glauconite, there is a pleochroitic yellowish-green chiorite-like crystallized glauconite, perhaps derived from biotite.

Amongst the micro-organisms are globular radiolarians (Spumellarians), and imperforate siliceous foraminifera *(Ophthalmididae)* recalling highly organized miliolids like *Nummuloculina.*

Tectonics of the Flysch

With a photogrammmetric map at hand it would be a pleasure to work out the intricate, though interesting structure of the Kiogars. The existing map, though remarkable, is entirely insufficient. Also, after having traversed only part of the country, we only can point out some characteristic features.

We have shown that the Himalayan Triassic surrounding the Kiogar region on the west, south and east side, forms regular folds of a nearly northern strike, with a pitch towards that direction. The overlying flysch separated from the Kioto limestone by the Spiti shales, has "proclaimed its liberty", in producing further deviations and disharmonic folding.

Thus, the upper Giumal sandstone of the peak above point 14110', of Sangcha Talla (see map of v. KRAFFT) forms a pointed arch anticline striking N 20—40° E! (Fig. 117)

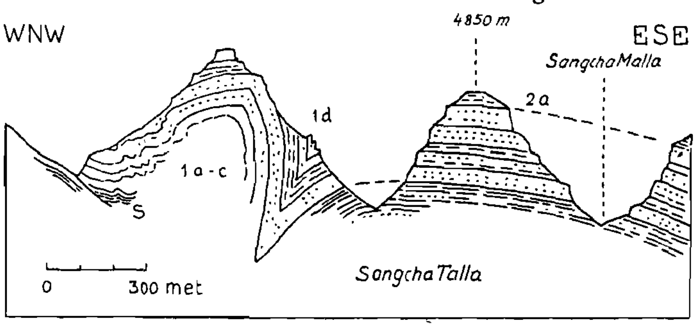


Fig. 117. Sketch of the Flysch structure at Sangcha. S = Spiti shale; 1 a—c = Giumal subdivisions; 1 d = upper Giumal sandstone; 2 a = green and red shale of upper flysch.

The flat-topped wild peak of upper Giumal sandstone capped with red shales at Sangcha Malla (4850 met.) is cut off by a fault of about 150 meters drop on the northeastern side (Fig. 115, 117). This fault, or a similar one, continues towards south, cutting an isolated block out of the Giumal sandstone on the south side of the Kiogar.

The beautiful fold of the upper Giumal sandstone SW of Kiogar Nr. 3 (see pl. 3 of v. KRAFFT, our Phot. 2 Pl. I and Fig. 118) and its southeastern side-fold, are striking N 45 E, with a pitch in that direction of 5—7°. Thus, this strike is at an angle of 50—60° to that of the adjoining Lahur anticline.

At the crest of Chaldu pass, the flysch sandstone strikes N 10 E. Independantly, these diverging flysch folds are covered by the white "Dachsteinkalk" of the great Kiogar Saw with its igneous rocks. The flysch of Himalayan facies thus is disharmonic to both its underlying and overlying formations.

In the Chirchun area, no observations on Flysch tectonics have yet been made. The structure may only be revealed by systematic mapping on a good topographic basis.

Balchdhura

The northwestern end of the Kiogar thrust sheet forms the Balchdhura crest. It is of special interest for its igneous varieties and exotic blocks enclosed, which are easily accessible. A few additional observations to those of v. KRAFFT will be described.

In the ravine, at about 5400 meters due west below Balchdhura 18110', discovered by

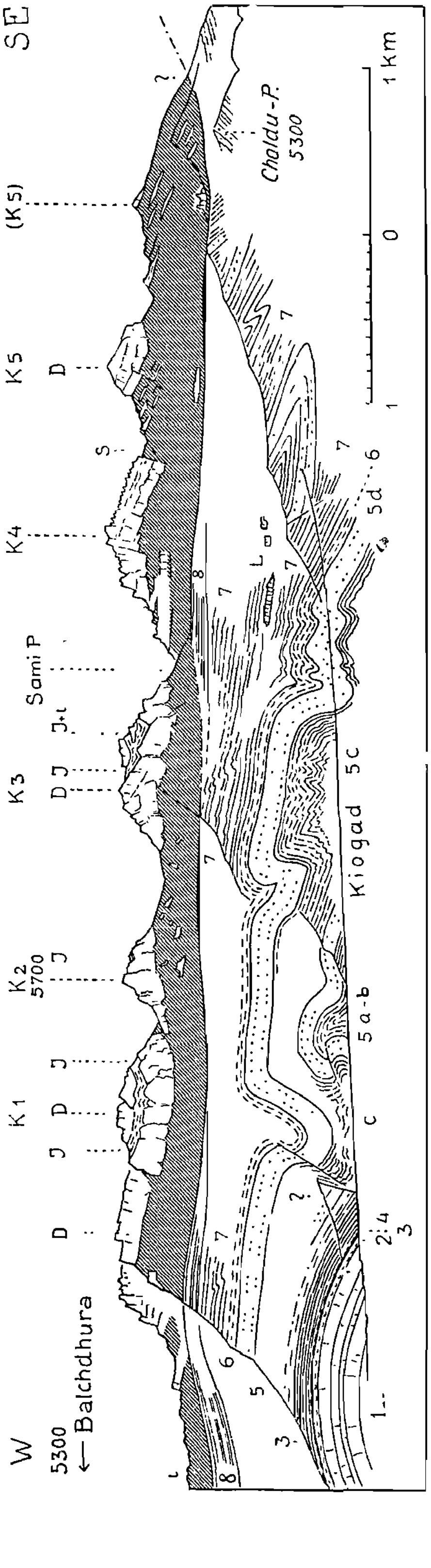


Fig. 118. The Kiogars K1—5. Tectonical Diagram in Projection to NE.

Note: the thickness of the formations is somewhat reduced on account of the dip or pitch towards NE. The faulted flysch zone at the left cannot be properly represented, since the faults run N to NNW, nearly parallel to the designing plane.

Himalayan Facies:

1 = Kioto limestone, up. Triassic; 4 = Spiti shale, up Jurassic; 7 = black flysch with fucoids;
2 = Laptal lumachelle, Liassic; 5a — c = Giumal sandstone, lower Cretaceous; 8 = Siliceous sandstone and radiolarian chert.
3 = Ferruginous Oolite, Callovian; 6 = green and red shales;

Tibetan Facies, Kiogar thrust sheet:

i = basic igneous, porphyrite, serpentines etc., including exotic blocks; J = Jurassic limestone, oolite;
D = white limestone, "Dachsteinkalk"; L = exotic blocks of Liassic limestone in flysch.

(Kiogar Nr. 5 on v. KRAFFT's map is at the wrong place. The peak Kiogar Nr. 5 of his panoramic view, pl. 3, is the same conical southeastern summit which he has mapped as Kiogar Nr. 4).

v. KRAFFT, are two red limestone blocks, both weathered out of the porphyrite, though still connected with it, and showing a striking contact metamorphism.

The larger block of deep sea facies, is made of nearly dense, brickred limestone, devoid of fossils. It forms a high pinnacle of steeply erected stratification (Phot. 44, Pl. XVII).

The smaller, and highly fossiliferous block is surrounded and intruded by porphyrite. The contact zone of 10—30 centimeters thickness is characterized by white calcite vesicles of some millimeters thickness, with which the medium basic rock of green and red colour is sprinkled. Also an inclusion of true volcanic tuff of the size of an egg was found in the porphyrite. From the smaller block[1] of about 4 × 4 × 1 meter, we collected the following Carnic Cephalopods (det. A. JEANNET):

Anatomites sp. Div.
Anatropites cf. *spinosus* MOJS.
Cladiscites crassestriatus MOJS.
Hypocladiscites subaratus MOJS.
Hypocladiscites subcarinatus GEMM.
Proarcestes cf. *Gaytani* KLIPP.
Arcestes cf. *decipiens* MOJS.
Arcestes sp. div.
Discophyllites sp.
Orthoceras sp. ind.
Aulacoceras cf. *Timorensis* WANNER.

[1] This is apparently the block Nr. 2 discovered by VON KRAFFT, of which DIENER (13 p. 136) gives a list of 40 species of ammonites.

On the opposite, southern side of the little ravine, and higher on the slope, are other large red limestone blocks of cubic shape, in which no fossils were found (e 3). There seems to be again one distinct horizon abounding with fossils, exclusively Cephalopods—perhaps a kind of condensation. There are few chances to find blocks just of this fertile layer.

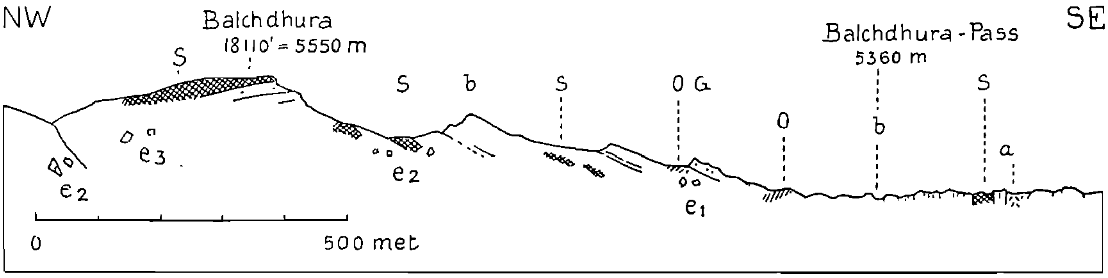


Fig. 119. Balchdhura Crest.
b = basic rock, greenstone, porphyrite; S = Serpentine; O = Ophicalcite; G = Greenish Sandstone block; e = exotic blocks, chiefly Triassic (see text).

Some 200 meters SE of the serpentine plateau of Balchdhura heights, are several angular blocks of well-bedded green and red hornstone with radiolarians, one of them bedded in serpentine the other in porphyrite. They belong either to the Triassic or to the upper flysch. Near them two round pebbles of gray, non-metamorphic limestone were noticed, each about a foot in diameter.

On the Tibetan side, below a big block of Giumal sandstone in greenish igneous with ophicalcite, an angular block of about 25 cubic meters was seen, showing a strongly slickensided basal plane.

It is difficult to distinguish in some places the glauconitic Giumal sandstone from certain varieties of the basic rocks. Thus, our Fig. 119 may need improvement. The microscopic examination, however, has confirmed v. KRAFFT's description, mentioning "exotic blocks" of Giumal sandstone. According to him the youngest rock embedded in the igneous is a strongly slickensided "green and red tuff" (his flysch 4 f), "due south below the western summit of the Balchdhura heights."

Another striking aspect of Balchdhura is the abundant occurrence of serpentine and ophicalcite. The former is greenish black and frequently intensely slickensided. Obviously, the igneous rocks have suffered strong tectonical deformation after their solidification (Phot. 45, Pl. XVII).

Two hundred meters SE of the pass (at a of Fig. 119), there is a great variety of basic rocks: Amygdaloid porphyrite, slickensided glassy serpentine, ophicalcite, locally also peridotite. They would deserve a special study.

The Kiogar Peaks

v. KRAFFT, with his masterful panoramic designs pl. 2 and 3, has already given a clear view on the topography and geology of this saw-like Tibetan frontier-range. There are some points, however, which need correction:

1) A good part of what is designed Nr. 5 = igneous, is brown Jurassic, and the "Dachsteinkalk" D is less broken.

According to v. KRAFFT's plate 2 and his section pl. 12, the mountains look like heaps of loose blocks. This is not the case. The stratification of the Kiogars, seen from the SW, is quite clear (Phot. 2, Pl. I) and not more shattered than many Triassic regions of the "Klippen" in the Alps (Fig. 118). Also intense folding within the formations of the Kiogars could be observed.

2) V. KRAFFT's mapping of the Kiogars as "exotic blocks" with blue ovals is contradictory to his own designs and still more so to nature. Indeed, we have found the limestone of the Kiogars extending to the Tibetan side for more than 20 square kilometers. Our photograph 46 Pl. XVIII gives an idea of it.

In climbing Kiogar Nr. 2 (5700 m), a closer study also resulted in establishing a stratigraphic sequence of the Kiogar thrust sheet.

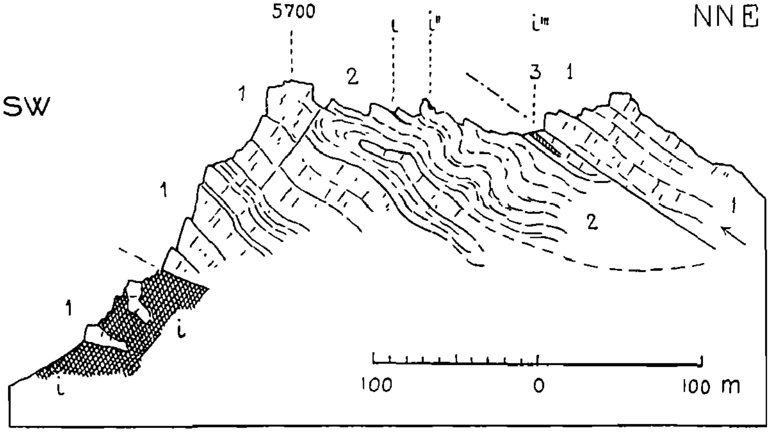


Fig. 120. Section of the Summit of Kiogar Nr. 2
i = igneous;
1 = white Kiogar limestone, "Dachsteinkalk";
2 = oolitic formation, upper Jurassic;
3 = gray radiolarian limestone, Cretacic.

1. The massive white Kiogar limestone of 200—300 meters thickness, rests upon basic igneous rocks. It is partly of dense to micro-cristalline, partly of onkolitic structure. No fossils were found. As suggested by v. KRAFFT, it may be a representative of the Alpine Dachsteinkalk. Upon it follows, with a sharp boundary (discontinuity):

2. Reddish to violet calcareous series,
   a) about 8 meters of reddish marls and limestone,
   b) about 50 meters of violet oolitic limestone of flaser-structure, interbedded with pink marly and white limestone layers;
   Under the microscope, the groundmass is partly dense, partly calcitic. The oolitic grains are made of dense, nearly untransparent lime, some of them being nicely concentric.
3. 12 meters of dense, stratified gray siliceous limestone, probably Cretaceous, full of micro-organisms.

The first appearance under the microscope is that of an *Orbulinaria*-limestone like the Alpine Seewerkalk, but the tiny "cogwheels" of 0,1—0,2 millimeters are partly siliceous and seem to be mainly globular radiolarians. Also Nasselarians are present, together with numerous sponge spiculae (Phot. 76 Pl. XXV).

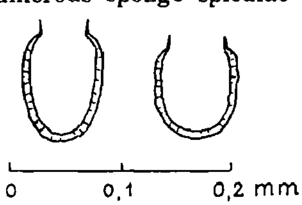


Fig. 121. *Calpionella alpina* LORENZ in the oolitic limestone of Kiogar Nr. 2.

In this sequence, no macroscopic fossils were met. Under the microscope, however, a few nicely preserved shells of *Calpionella alpina* LORENZ were found in the groundmass of the oolitic limestone 2 b (Slide Nr. 6). The form of the tiny vases somewhat converges to *Calpionella elliptica* CADISCH (Fig. 121), both species being characteristic for the uppermost Jurassic, and the passage to Berriasian. We thus may hardly fail to attribute the Kiogar Oolite to the Portlandian (Tithonian).[1]

This sequence is intensely squeezed, folded, thrust and faulted. The northeastern summit of Kiogar Nr. 2, nearly as high as the

[1] CADISCH, JOOS, Ein Beitrag zum Calpionellen-Problem. Geol. Rundschau Bd. XXIII, a. 241—257, 1932 and CASANOVAS, G. COLOM, Estudios sobre las Calpionelas. Bol. Soc. Española de Historia Natural t. XXXIV, op. 379—388, Madrid 1934.

main peak, is again made of Kiogar limestone, which overlies the gray limestone with a thrust plane of 35° dip to N 5° E (Fig. 120).

Not only is the Kiogar series tectonically tormented, but also injected. The basic intrusions into the Kiogar limestone from below were well-known by v. KRAFFT, although exaggerated. But even on the top of Kiogar Nr. 2, and within the younger Jurassic formation were found small green igneous intrusions (i', i'', i''' in Fig. 120). The most interesting of them is i'' (Fig. 122).

There, the little peak of green diabase, originally a sill, is folded together with the brown to pink Jurassic oolite and its white limestone layers. This statement is conform to the many observations of intensely disturbed and slickensided basic igneous rocks already made by v. KRAFFT. Indeed, they have not been intruded at their actual position, but before being folded and thrust.

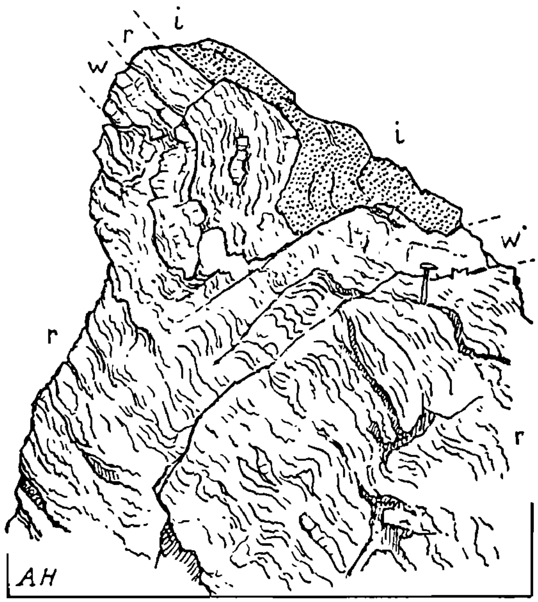


Fig. 122. Detail of Kiogar Nr. 2 at 5650 meters.
r = pale red to violet upper Jurassic limestone with white limestone layer (W),
i = green basic igneous rock.

With the above observations of detail at hand, we are looking around. On the north.side of our Kiogar Nr. 2 is Kiogar Nr. 1. The following Fig. 123 is drawn at a distance, and can only give an approximate idea of what may be expected by a detailed research.

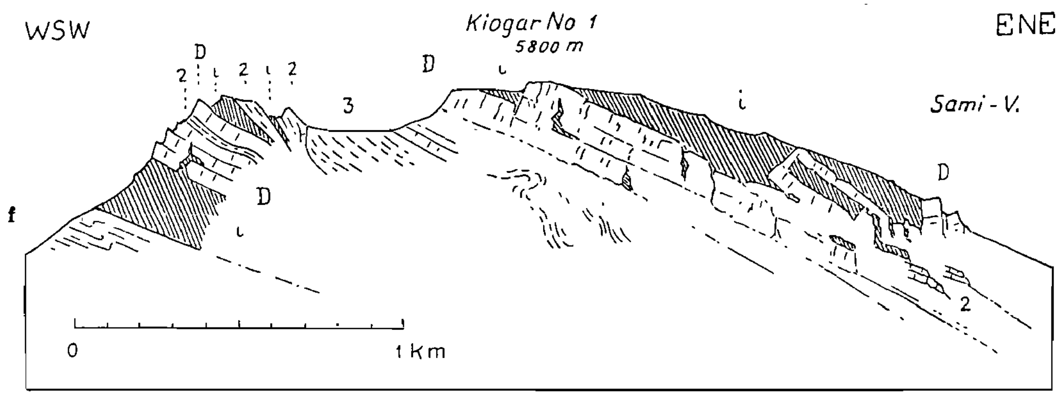


Fig. 123. Profile View of Kiogar Nr. 1, sketched from the top of Kiogar Nr. 2.
f = black flysch shale; i = basic igneous; D = Kiogar limestone; 2 = pink limestone and shale, oolitic formation, Jurassic; 3 = thinbedded gray to pink limestones and shales (Cretaceous?).

The above observation is confirmed by the distance view of the Kiogars from the SW (Fig. 118). Therefrom we notice a brownish band within the walls of Kiogar Nr. 1. Corresponding traces are also seen on Kiogar Nr. 2 and Nr. 3.

In order to get a glimpse of the folding, we go over Sami Pass between Kiogars Nr. 3 and 4 to their northeastern side. There we see several repetitions of infolding of the Kiogar limestone with pink Jurassic (Fig. 24). The reddish Jurassic band on the south side below the summit of Kiogar Nr. 3 also contains igneous intrusions like Kiogar Nr. 2.

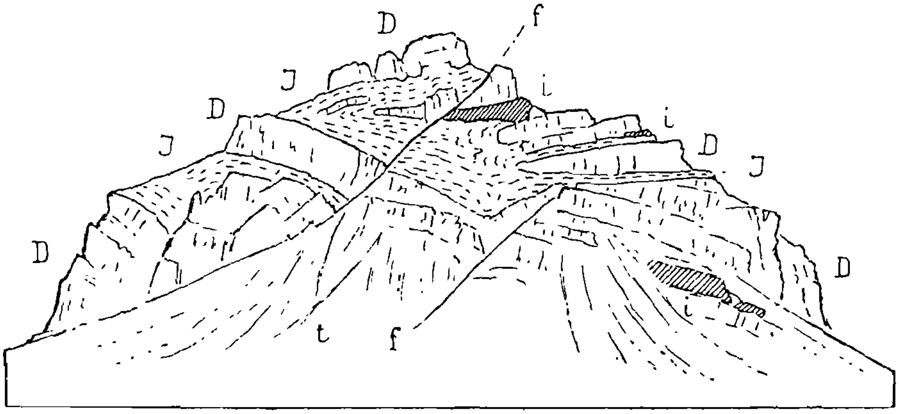


Fig. 124. Sketch-view of Kiogar Nr. 3 from the upper part of Sami Valley, looking up towards SW.
D = Kiogar limestone; J — pink Jurassic; i = igneous; f = fault; t = talus

Similar injection, folding and faulting is seen on the NE of Kiogars Nrs. 2 and 4. This observation would be sufficient to exclude the origin of the Kiogars by volcanic explosions!

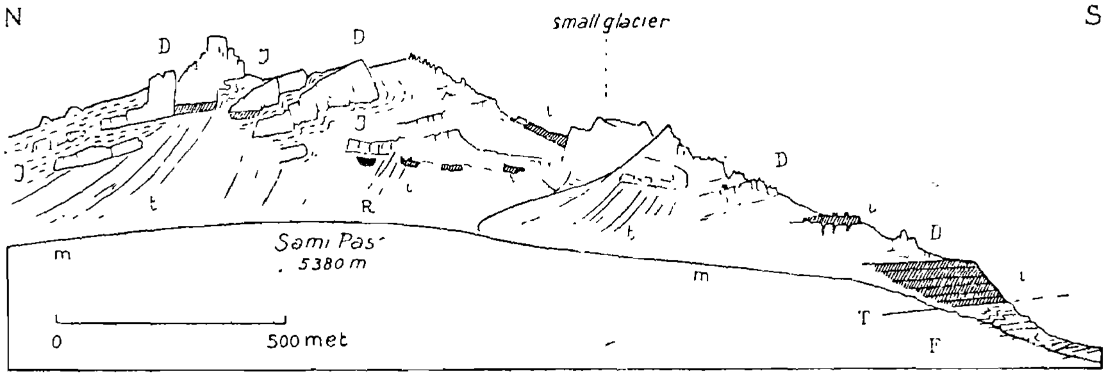


Fig. 125. Sketch fo the east side of Sami Pass.
D = Kiogar limestone; J = red Jurassic; i = basic igneous; R = red hornstone, Triassic (?); F = Siliceous flysch, radiolarian chert; T = Kiogar thrust; t = talus; m = moraine.

Additional members of the Kiogar series will possibly be found in the future below the "Dachsteinkalk" and above the gray radiolarian limestone.

Unfortunately, the thrust plane of the igneous upon the flysch is usually covered with talus. On the other hand, the time at our disposal was insufficient to hunt after places of contact. The only chances for putting hands on the contact seem to be above Sangcha Malla, and in the ravine south of Sami Pass (Fig. 118, 125, 127). In agreement with v. Krafft, and in opposition to C. Diener, igneous rocks in the form of dykes traversing the mesozoic Himalayan formations were found in no place. Where they are found in the flysch, they are tectonically infolded.

The Exotic Blocks South of the Kiogar Peaks

We have to distinguish three series of exotic blocks:

1) those enclosed in the igneous at the basis of the main Kiogar thrust plane,
2) those in the flysch,
3) those enclosed in or connected with the igneous on the south side of the Kiogar.

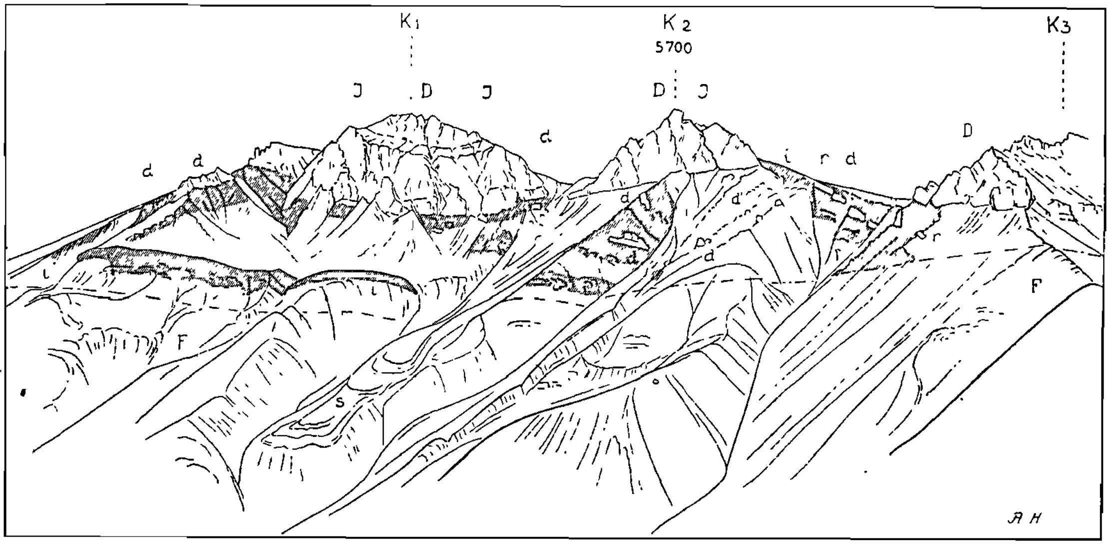


Fig. 126. View of Kiogars Nr. 1 and 2 from a flysch hill 5100 meters SW of Kiogar Nr. 3, looking north.

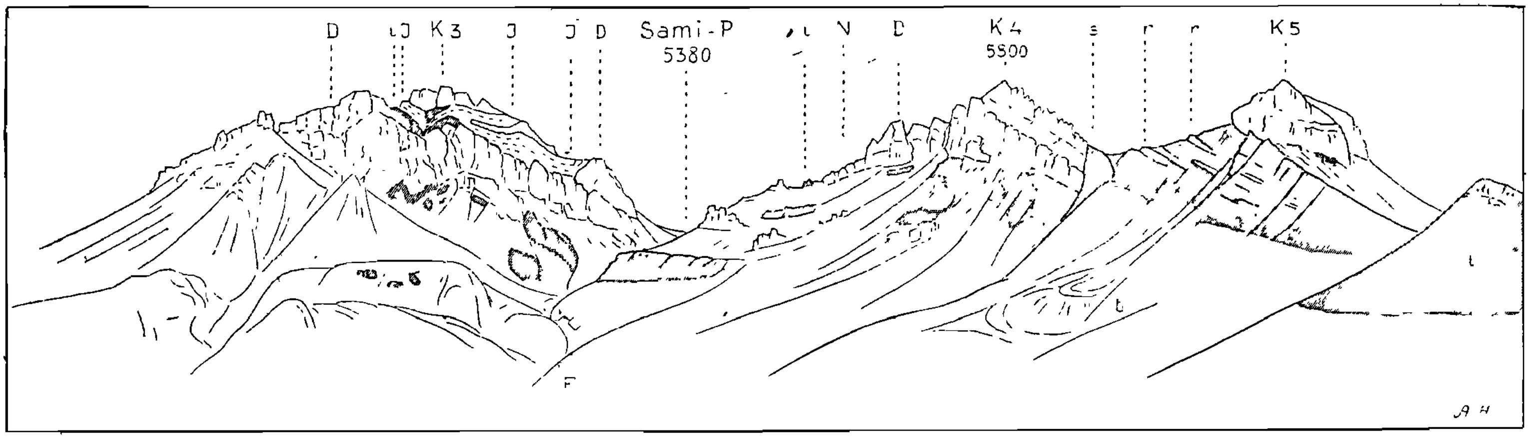


Fig. 127. Panoramic view of Kiogars Nr. 3, 4 and 5 from NW of Chaldu Pass at 5200 meters, looking north (K3 = N30W, K5 = N30E). D = Kiogar limestone (Dachsteinkalk); J = Upper Jurassic limestone; F = black flysch shale; r = red radiolarian hornstone; i = basic igneous; S = Serpentine; d = blocks mixed with igneous. T = thrust plane; t = streams of talus from white Kiogar limestone; s = solifluction.

1) Numerous blocks are known, and many more could be located by hard climbing with sufficient time, within the basic igneous, on the basis of the Kiogar thrust sheet. A most interesting place is the south side of the gap between Kiogars Nr. 2 and 3. There, numerous angular blocks of small and large size stick out of the green igneous, especially red radiolarian chert and white Kiogar limestone (Fig. 126).

Red chert with radiolarians and associated, more or less siliceous limestones and marls are abundant in the southeastern Kiogar region. On the saddle between K 4 and 5 (after Gansser), and on the igneous crest north of Chaldu Pass, these rocks and flags occur in such abundance that they form a kind of stratification. The question whether these red limestones and cherts are Triassic or of upper flysch origin, is still open.

Near the basis of the Kiogar thrust, connected with the igneous, but possibly slipped down by sacking, are several "Klippen" of white, massive Kiogar limestone. The most prominent one was photographed by v. Krafft (36 pl. 7). The left (western) hill is made of upper flysch sandstone below the thrust plane, not igneous (Fig. 128).

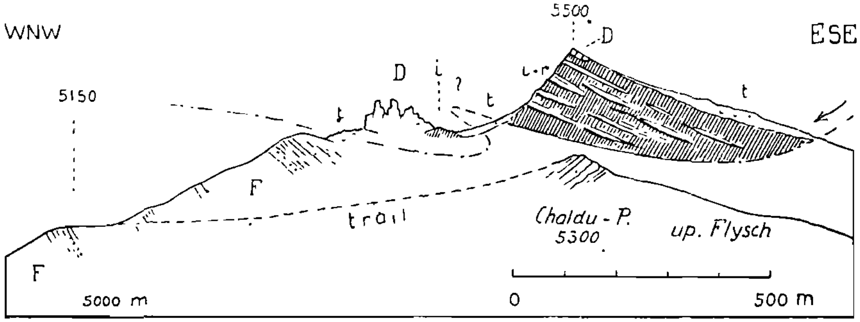
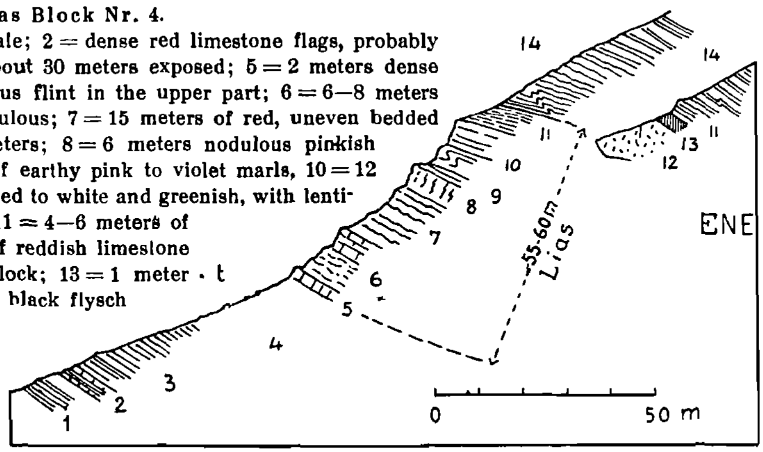


Fig. 128. Section of the "Klippe" at Chaldu (=Kiogar) Pass.
D = Kiogar limestone; i = basic igneous with chert layers; F = upper siliceous flysch sandstone; t = talus; T = Kiogar thrust.

2) In the flysch on the slope south of the Kiogar peaks, v. Krafft already has found the most prominent exotic blocks, and determined them as Liassic limestones (Nrs. 4—7). The most prominent one is EB 4 of v. Krafft's pl. 3, which corresponds to our Fig. 129.

Fig. 129. Section of the Exotic Lias Block Nr. 4.
1 = black to green and red flysch shale; 2 = dense red limestone flags, probably flysch; 3 = gray and black flysch, about 30 meters exposed; 5 = 2 meters dense gray to pink limestone, with breccious flint in the upper part; 6 = 6—8 meters gray dense limestone, lower part nodulous; 7 = 15 meters of red, uneven bedded limestone layers each 5—20 centimeters; 8 = 6 meters nodulous pinkish limestone with flint; 9 = 2 meters of earthy pink to violet marls, 10 = 12 meters well-bedded dense limestone, red to white and greenish, with lenticular flint layers and radiolarians; 11 = 4—6 meters of earthy red marly shale; 12 = block of reddish limestone breccia at the eastern end of the block; 13 = 1 meter of green basic igneous; 14 = gray to black flysch shale with reddish and greenish layers; t = talus.



Thus, this largest of all blocks in the flysch has a thickness of about 60 meters. Its visible length is 200 meters. The total length may be 250—300 meters. This huge longitudinal

block, as a whole, is conformably enclosed in the upper flysch, with a dip of 10—20° towards E and NE (see also Fig. 118).

In other blocks of the same facies, v. KRAFFT has found numerous *Arietites* and *Phylloceras*. He says: "This is the first record of Lias fossils in India. My specimens are in preservation identical with the Lias of Adneth near Salzburg (Austria). This type of block is the most characteristic of all, and once closely observed, can be recognised from afar by its characteristic tint".

The exotic Liassic is of a deep sea facies. This is confirmed again by the microscope, which reveals an entirely dense limestone with altered radiolarians, and numerous sponge spiculae, whilst the flinty part is a true radiolarian chert of an amorphous groundmass. The globular radiolarians are filled with fibrous chalcedony, while the shells have disappeared.

Some hundred meters east of E B 4 is a Liassic block of about 20 meters height and 10 meters thickness, its strata being contorted and partly vertical, striking E 25 N. Green igneous rock sticks on its northeastern wall.

In the ravine follows v. KRAFFT's block 6, which has a north-south length of about 100 meters, and, too, is associated with green igneous blocks. They follow in a row the Liassic limestone. The flysch, however, in which these blocks 5 and 6 must be enclosed, is not exposed.

3) The exotic blocks on the south side of Kiogar, numbered 9—20, have been mapped and partly described and figured (Nrs. 17, 18, 19), by v. KRAFFT. Unfortunately we were forced to return to Almora, and were therefore unable to set foot on this highly interesting region of exotic blocks. It is well exposed and in parts not difficult to climb. Photograph 48 Pl. XVIII shows the characteristic flysch erosion, the disposition of the exotic blocks and of the igneous in which they are enclosed.

The tectonical position, as a whole, seems to be as follows:

The basic sheet, of a thickness up to several hundred meters, is more or less conformably intercalated between black shales of the upper flysch, with a dip of 15—30° to ENE or SE. The exotic blocks are chiefly at the basis, though some of them are also in the middle and upper part. According to the map of v. KRAFFT, most of them are Permian limestones (Nrs. 9, 11, 13, 15, 18, 19), two are fossiliferous lower Liassic of the Alpine Adneth facies (16, 17) and one is Triassic of Hallstadt facies (20). With their red colour, they are recognized on the dark igneous ground at a long distance. The most prominent and topographically lowest one is the Permian block Nr. 9 (Phot. 48)[1].

The igneous sheet between the flysch, enclosing the exotic blocks Nrs. 9—20 is unquestionably a thrust sheet. It is in no connection with that of the Kiogars. The big Liassic blocks Nr. 4—7 in the flysch south of Kiogar Nr. 3, may represent the continuation on the north side of the Kiogar Valley, where the thrust sheet is torn into pieces with only subordinate remains of igneous rocks accompanying the exotic limestone blocks (Fig. 132).

The Chirchun (= Chitichun) Area

Looking down towards east from Chaldu Pass[2], the view for the common traveller is monotonous and uninteresting, but fascinating to the geologist. It is a dark, dreary and gloomy landscape, of upper flysch, intersected by numerous small valleys, of which the crests between are capped by pink to red limestone rocks—a crowd of exotic blocks, of which about a dozen

[1] Here the map of v. KRAFFT is not quite correct. This block, as shown on his plate 4, does not rest directly upon Giumal sandstone. His geological mapping was based on a too inaccurate topography, and needs revision in such questions of detail.

[2] On the old map 1" = 1 mile called Kiogarh (Chaldu) Pass 17440', on v. KRAFFT's publication pl. 11 called Chirchun-Chaldu, and in the top. Sheet 62 B, 1" = 4 miles Kiogar Pass.

can be seen at a glance. As we had to traverse the country in a haste and in bad weather, we best revert to the excellent design of v. KRAFFT (36, pl. 11).

Here the question arises, whether these blocks represent the weathered relics of one continuous thrust sheet of exotic rocks, or whether they have already been isolated in the flysch during the advance of the thrustmass, as is the case with the Liassic blocks below the Kiogars. A special study would be necessary to solve this problem. For this purpose, a topographic basis which is not yet existing of this region, would have to be surveyed first. Obviously, some of the blocks have been sacking, especially where the erosion has commenced to remove their underlying flysch.

Most of the exotic tops, and the larger ones especially, have been given the Nr. 10 by v. KRAFFT, which means "blocks of uncertain age", while those of the Chirchun Nr. 1, 17740′ were determined by their brachiopods as Permian, with a very small one between them, which is Triassic.

The only small excursion we could make, was from Chirchun encamping ground to Chirchun Nr. 1, where GRIESBACH found already in 1892 *Fenestella, Trilobites* and Paleozoic brachiopods. The observations of v. KRAFFT were confirmed, except that we regard Chirchun Nr. 1 as being made of different blocks, separated by siliceous flysch shale (Phot. 49, Pl. XVIII).

The flysch hills are rounded and the slopes are creeping. Everywhere, solifluction is at work, and the structure of the flysch usually is inextricable.

An interesting block or group of blocks is v. KRAFFT's Nr. 9 b, about 800 meters WSW of Chirchun Nr. 1 (Fig. 130).

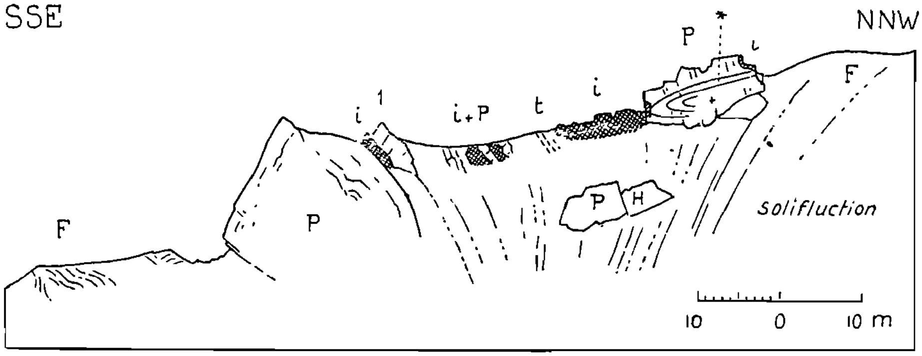


Fig. 130. Profile view of the Exotic Blocks 9 b, WSW of Chirchun Nr. 1. P = massive white to brownish crinoid-limestone with *Productus* and an ammonite at +; violet layer with Crinoids and Corals at *; H = red and white Triassic limestone; i = basic igneous; t = local spot of greenish breccious true volcanic tuff; F = upper siliceous flysch shale, green-red-black, with radiolarians, under solifluction.

Already v. KRAFFT mentions half way between this block and Chirchun Nr. 1 a small block of red Triassic limestone in the flysch. Of this "MIDDLEMISS crag", which is full of ammonites, DIENER mentions *Ceratites (Danubites)* and other "Muschelkalk" species (13 p. 135). The siliceous flysch in which the block is embedded, contains breccious red radiolarian chert with opal as a ciment.

The great block of Chirchun encamping ground indicated by v. KRAFFT as of uncertain age, is Permian crinoid limestone. Its deep position, nearly touching the Laptal lumachelle and the Spiti shales, opens the question, how much is to be attributed to post-tectonic sacking. Part of this unusual position, however, seems to be related to a syncline, like the more western occurrences. All such questions call for a new topographical basis.

Overlooking the Chirchun region, the resemblance with the exotic region south of the

Kiogar is obvious. In both areas the Permian blocks are predominent, while only one Permian block was found in the Kiogar thrust sheet (at Sangcha Malla, 36 p. 140).

We thus propose to call this tectonically lower exotic story the Chirchun thrust sheet.

Morphological Remarks

The predominent feature of the landscape in the Kiogar region is the flysch and its cap of Kiogar limestone. The flysch presents little obstacle to water erosion, so that the ravines have progressed backwards and cut out the peaks of a formerly wider thrust sheet of limestones.

Over vast extensions, especially in the Chirchun region, solifluction governs the rounded shape of the flysch slopes. Also the fragmen of white Kiogar limestone, which fall down from the peaks, are gradually flowing on their unstable substratum, helped perhaps by snow and certainly by the frequent freezing and unfreezing of the ground. Glacier-like streams have been observed on the SW-side of Kiogar Nr. 5 (Fig. 127) and in a still more fascinating way, with a concentric tongue, coming down like a glacier, from Kiogar Nr. 2 (Fig. 126 and Phot. 47, Pl. XVIII).

Regarding the summits from Balchdhura to Kungribingri, they are all of similar height, namely between 5700 and 5900 meters. The only glacier we met is a small hanging glacier on the north side of Kiogar Nr. 4 (Fig. 125), which comes down to about 5500 meters only. The upper Sami Valley partly seems to be filled with coarse and little worked ground moraine. Also the irregular hills and terraces south of the Kiogars may be due to former glaciation and firn fields. But no true moraine was encountered in the Kiogar Valley and its branches.

An interesting topographic feature is the great fjord-like lake of Chirchun. (Chitichun 16130' = 4950 meters) of the top. Sheet 62 B, 1" — 4 miles. It is, however, only a field of gravel, accumulated by the glacier streams coming down on both sides of the Chitichun Nr. 2, 19550 (nearly 6000 meters). It is probably a filled-up lake dammed by a Pleistocene moraine.

The river originating at the joint glaciers west of Chitichun Nr. 2 has cut a deep gorge into the anticlinal Kioto limestone, which ends before the gravel plain (Fig. 133).

Towards north, the Tibetan country is more and more governed by talus and gravel. The latter, after A. Gansser, forms extended high terraces on the west side of the anticlinal Kioto limestone ridge of Chaldu Nr. 2. A close study of this forbidden ground would be of the highest interest.

Solved and unsolved problems—Comparison with the Alps

At the time when C. Diener (1898) and v. Krafft (1902) discussed the problem of the exotic blocks in comparison with the exotic regions of the Alps and the Karpathians, the latter regions were yet insufficiently known. V. Krafft came to the conclusion "that the exotic blocks of Johar and Chirchun have nothing whatever to do with the 'Klippen' of Europe. While none of the European occurrences are connected with igneous rocks, their origin being according to all accounts due to structural causes, the exotic blocks of Tibet and the adjoining frontier districts are intimately connected with volcanics, and owe their existence to volcanic action". V. Krafft thus did not know the basic igneous sheets of the Vorarlberg-Allgäu-Klippen, nor the fundamental work of Quereau on the Klippen of Iberg[1], who described and mapped scattered diabase porphyrite intimately connected with the "Klippen" and their radiolarian chert over an area of several square kilometers[2].

[1] Ed. Quereau, Die Klippenregion von Iberg, Beiträge z. geol. Karte der Schweiz, Lfg. 33, 1893.

[2] A. Jeannet, in Alb. Heim, Geol. d. Schweiz Bd. II b, p. 664, and
Excursion de la Soc. géol. Suisse dans les Alpes de Schwytz,
Eclogae geol. Helv. Vol. 28, Nr. 2, 1935.

A few years after v. KRAFFT's paper the main tectonical problem in Switzerland was solved in the sense of MARCEL BERTRAND[1], SCHARDT[2] and LUGEON[3]:

The exotic regions are the remains of great "lambeaux de recouvrement". However, ARNOLD HEIM[4] showed that two kinds of "exotic blocks" must be distinguished:

a) blocks of rocks pertaining to the thrust sheets, and tectonically embedded in the flysch ("Klippenblöcke", "Schürflinge") and
b) the ordinary exotic blocks like Habkern granite, porphyry, polygenic breccias, which are stratigraphically embedded in the Wildflysch[5]. The latter are chiefly acid rocks unknown in the thrusted "Klippen"-sheet itself.

In the Kiogar region of the Himalaya, exotic blocks like those of the ultrahelvetic Wildflysch are unknown. The sedimentary blocks known so far are of Permian and Mesozoic age, embedded in the igneous with contact metamorphism or, if embedded in the flysch, still showing in most cases an intimate association with basic igneous rocks. There are also blocks exclusively of igneous origin. But there are other delicate questions:

1) The exotic fossiliferous rocks of Permian, Triassic and Liassic age are of a facies yet unknown in the stratigraphic seqnence of the Kiogar thrust sheet;
2) Not only exotic blocks of an unknown facial origin are found in the igneous. Already v. KRAFFT has found Giumal sandstone blocks in the diabase of Balchdhura, and we must confirm this observation. After a microscopic test it is at least certain that the basic igneous contains sandstone blocks of flysch facies similar to that of the Giumal sandstone. Besides this, part of the frequent siliceous shales with Radiolarians embedded in the diabase may belong to the flysch. We thus would have enclosed in the basic igneous rocks, or in the flysch, representatives of three different facies:
   a) Blocks of the Kiogar facies (chiefly in the igneous of the Kiogar thrust sheet). Only the white Kiogar limestone of this type has so far been found, regarded as "Dachsteinkalk".
   b) Blocks of sedimentary rocks of an exotic facies unknown in situ (Permian, Triassic, Liassic). This facies is of a deep sea[6] character, and totally different from the Himalayan facies forming their tectonical substratum, but also completely different from the Kiogar series. We may call it the Chirchun facies.
   c) Blocks apparently of flysch facies, similar to the Cretacic Giumal sandstone of the Tethys Himalaya. V. KRAFFT mentions also blocks of upper flysch in the diabase.

The idea that the exotic blocks and the Klippen of the Kiogars were thrown over to the Himalayan border by huge volcanic outbursts in Tibet, is rejected by the following observations:

1) The exotic blocks and the igneous rocks are frequently squeezed and slickensided. In one place (Kiogar Nr. 2), we have found the igneous intrusion folded together with the Jurassic. The igneous rocks have suffered the same tectonical disturbances after their solidification as the adjacent rocks in which they have been intruded.

2) The Kiogar limestone extends over many square kilometers, and permits to recognize its stratification over considerable distances.

3) Above the Kiogar limestone follows normally a series of Jurassic to Cretacic calcareous sediments, which are folded and faulted together with the Kiogar limestone.

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[1] BERTRAND, M., Rapport de structure des Alpes de Glaris et du Bassin houiller du Nord, Bull. Soc. géol. France, 1883—84, p. 318,
BERTRAND, M. et GOLLIEZ, Les chaînes septentrionales des Alpes Bernoises, Bull. Soc. géol. France, 1897.

[2] SCHARDT, H. Sur l'origine des Alpes du Chablais et du Stockhorn, en Savoie et en Suisse, C. R. Acad. Sc., Paris, vol. CXVII, p. 707
Sur l'origine des Préalpes romandes, Arch. d. Soc. Phys. et Nat. Genève, vol. XXX

[3] LUGEON, M., Les grandes nappes de recouvrement des Alpes du Chablais et de la Suisse, B. S. G. France 1901, p. 723.

[4] HEIM, ARN., Zur Frage der exotischen Blöcke im Flysch etc., Eclogae geol. Helv. vol. IX, 1907

[5] see also ARN. HEIM, in ALB. HEIM, Geol. d. Schweiz, Bd. II. 1919, p. 356—360.

[6] v. KRAFFT (l. c. p 150) stated that "a careful examination in connection with the occurrence of breccias proves them (the Hallstadt- and Adneth facies) to have been formed in comparatively shallow-water". He seems not to have considered that the most frequent earthquakes occur in the deepest sea channels, nor did he notice the Radiolarites of the Kiogar region.

4) The summits of the Kiogars Nrs. 1—4, although separated by erosive gaps, show corresponding intense folding of the Kiogar series. Thus the band of reddish Jurassic marl and oolite could be followed already at a distance over the tops of Kiogars Nrs. 1, 2 and 3.

5) The "tuff 4 f" of v. KRAFFT is a siliceous radiolarian chert, which has nothing to do with volcanic action.

6) The igneous rocks at the basis of the Kiogar peaks are thrust upon this upper flysch of deep sea facies, or upon the black shale series of the upper flysch.

All these observations plainly result in the conception that the **Kiogars are the remains of a thrust sheet** coming from the Tibetan side, as already supposed inspite of v. KRAFFT's contradictory conclusions by E. SUESS, F. KOSSMAT and E. B. BAILEY. The complete difference of facies from the Himalayan substratum (in analogy with the Alps), proves that this thrust mass derives from a long distance.

The problem, however, is two-fold. In no place we yet know a Permian to Liassic sequence of the Chirchun facies with its deep sea limestones and radiolarian cherts of Triassic and Liassic age. We only know the scattered blocks. Is their original home of sedimentation this side of that of the Kiogar sequence, or beyond the former Kiogar basin still farther northeast in Tibet?

Possibly the blocks of Chirchun facies belong to an involved frontal part of the Kiogar thrust, torn into pieces and overrun by the back part of the Kiogar sheet. But even if so, the primary distribution of the exotic blocks and their embedding in the basic flow still is a problem by itself, considering that most of these blocks belong to the Chirchun facies, different from the Kiogar series. That the basic igneous basis of the Kiogar thrust sheet embraces blocks of all three facial types, is a fact which has no equivalent in the Alps. The following table shows the distribution of the three facies in the Kiogar region (thick line = discontinuity; interrupted line = contact unknown):

	Himalayan Facies	Tibetan Facies	
	Lahur anticline	Kiogar facies, main thrust sheet	Chirchun facies, fossiliferous exotic blocks of Chirchun and Kiogar
		Basic Igneous	Basic Igneous
Cretaceous	Upper flysch series of Kiogar Giumal sandstone	Shale and gray limestone with radiolarians	
Jurassic	Spiti shale (Portl).	Pink oolite and shale with *Calpionella alpina*	
	Ferruginous oolite (Callov.)		
	Laptal—lumachelle		Adnether Kalk with radiolarian chert
Triassic	Kioto limestone Kuti shale	Kiogar limestone ("Dachsteinkalk") 200 mt.	Red limestone rich in Carnic ammonites Red middle-Triassic limestone with *Ceratites* (Adnether Kalk to *Ceratites* limestone: deep sea-facies)
	Kalapani limestone Chocolate shale		
Permian	Kuling shale		Crinoid limestone with brachiopods

The above distinction of two exotic Tibetan facies is based on the supposition that the Kiogar limestone represents the Dachstein kalk. Should it be upper Liassic or middle Jurassic, there would be no necessity to accept two different Tibetan facies.

Regarding the age of the basic igneous, we can state that it is not only younger than the unfossiliferous Kiogar limestone, which has been pierced in hundreds of places, but also younger than the oolitic formation, and the gray radiolarian limestone, which, at the summit of Kiogar Nr. 2, also contains basic igneous. The igneous intrusion thus was cretaceous or post-cretaceous, and pre-thrusting, though possibly only partly pre-tectonic.

The relation of the basic igneous or ophiolites with the radiolarian chert is striking. The igneous flows must have been in relation to the deposition of the youngest sediments of the region which are regarded as upper Cretaceous deep sea deposits. In the southeastern Kiogars both are even mixed in a way as if the flow had penetrated and imbibed the flysch series chiefly along the bedding planes as it could hardly have been the case at the subaerial surface. Another point in favour of submarine flows and intrusions is the almost complete absence of true tuffs. All the primary phenomena, however, have been so much disturbed and displaced by tectonical movements that it is the most intricate task of Himalayan geology to reconstruct the primary conditions of the Tibetan facies.

Yet we have to draw the attention again on certain similarities or even complete harmony with the "Klippen" of the Alps, which are now studied and mapped in detail, although the last word has not been spoken either.

When looking the first time up to the fine peak of Kiogar Nr. 2 shown in Fig. 126, I called it in my diary the Mythen. Not only the shape recalls that famous "Klippe" of Central Switzerland[1], but also numerous other analogies have been found with the Klippen of the Mythen and Iberg:[2]

a) Their position and conservation in a synclinorium of the normal Tethys facies with flysch;
b) the non-existence of igneous dykes penetrating the substratum;
c) the stratigraphy of the Kiogars with Triassic, Jurassic and Cretaceous limestones corresponding to the Swiss Klippen of the same sequence;
d) the tectonics of the Kiogars showing intense folding and fracturing of a shallow structural type, like the Swiss "Klippen";
e) the long distance thrusting of an "exotic" facies;
f) possible involvements of secondary thrust sheets in the flysch;
g) the occurrence of strata being broken, torn in pieces and embedded in the flysch ("Klippenblöcke").
h) the occurrence in both cases of diabase or porphyrite showing igneous contact with the mesozoic strata of a deep sea facies. Indeed, the red Jurassic deep sea marl of Iberg (Schwytz) is exactly of the same type as several blocks found in the diabase of Balchdhura.

Thus, at the end of our discussion, we return to that remarkable general coincidence of deep sea deposits with ophiolitic[3] igneous rocks, as recognized first by G. STEINMANN after his observations in the region of Iberg, Schwytz. It was explained by submarine lava flows and intrusions in deep oceanic depressions. For the northwestern Himalaya, WADIA[5] already has demonstrated submarine flows of late Cretaceous or early Eocene time, and BAILEY[6] has compared these occurrences with those of the much older tectogenetic cycles of Scotland.

[1] ALBERT HEIM, Geologie d. Schweiz, II b, p. 656—665.

[2] A. JEANNET, Exkursionsbericht, Eclogae geol. Helv. 1935.

[3] Under ophiolite -- greenstones of E. SUESS, STEINMANN united the following types: Serpentine, ophicalcite, spilite, diabase-porphyrite, variolite and gabbro.

[4] STEINMANN, G., Die SCHARDT'sche Überfaltungstheorie und die Bedeutung der Tiefseeabsätze und der ophiolitischen Massengesteine, Ber. Nat. Ges. Freiburg, vol. 16, 1905.

[5] D. N. WADIA, On the Cretaceous and Eocene volcanic rocks of the great Himalaya Range in North Kashmir. Records geol. Survey of India, vol. 68, 1935, p. 419.

[6] E. B. BAILEY, Sedimentation in Relation to Tectonics. Bull. geol. Soc. Am. vol. 47, 1936, p. 1713—1723.

As a preliminary view, subject to alteration, it is supposed that the ophiolitic flows and intrusions occurred in late Cretaceous or Eocene time in a remote Tibetan zone on the southside of the Transhimalaya at the bottom of the deep sea and below it. Blocks slipped down from the coast and where embedded in igneous flows. Then followed the thrustidg towards south.

But although our observations prove the existence of long distance thrusting, there are two big problems still to be solved:

1) the way how a submarine igneous flow could embrace huge blocks belonging to three different facial regions;

2) the mecanics of long distance thrusting of a thin and superficial sheet, its tectonical decay and involvment in the Himalayan flysch.

These problems are even more intricate than those of the Alps, not to speak of the difficulties of travelling in such remote, uninhabited and even forbidden countries.

In the next chapter the problems touched above shall be approached again, after new observation in hitherto absolutely unknown Tibetan regions.

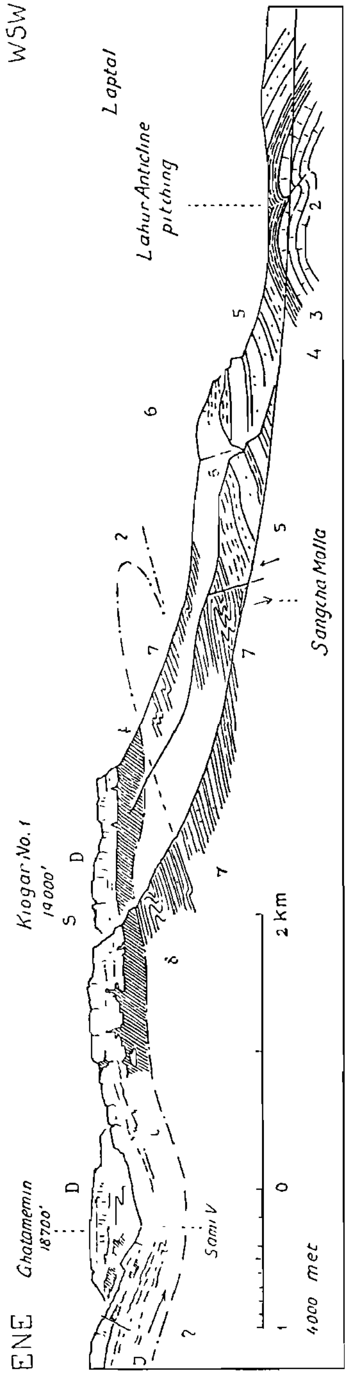


Fig. 131. General section from Kiogar Nr. 1 to Laptal

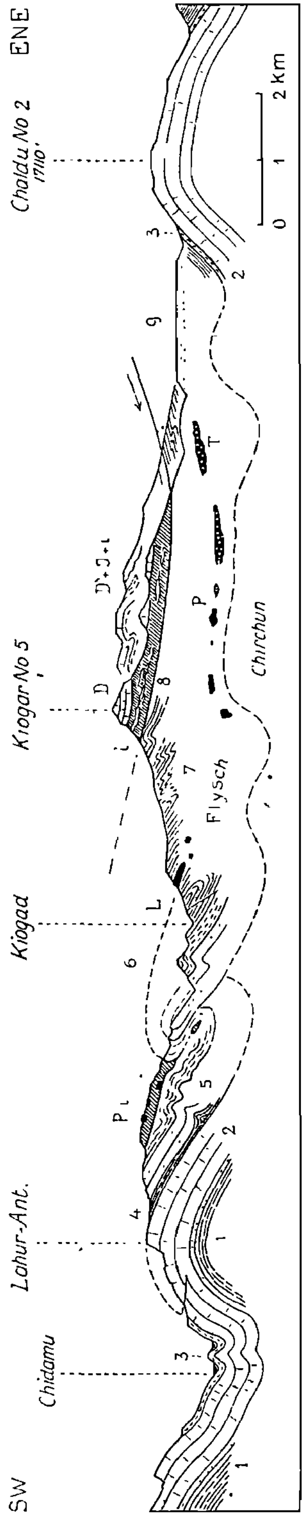


Fig. 132. General section from Kiogar Nr. 5 to Chidamu

Explanation for both figures above:
1 = Kuti shales, Noric; 2 = Kioto limestone, Rhaetic; 3 = Laptal series, Liassic; 4 — Spiti shales, Portlandian; 5 = Giumal sandstone, lower Cret.;
6 = green and red calcareous Flysch shales; 7 = black Flysch shale (with chondrites); 8 = Radiolarian chert.
i = basic Igneous partly mixed with Flysch; D = Kiogar limestone ("Dachsteinkalk"); J = upper Jurassic limestone
Exotic blocks: P = Permian; T = Triassic; L = Liassic; 9 = quaternary conglomerate.

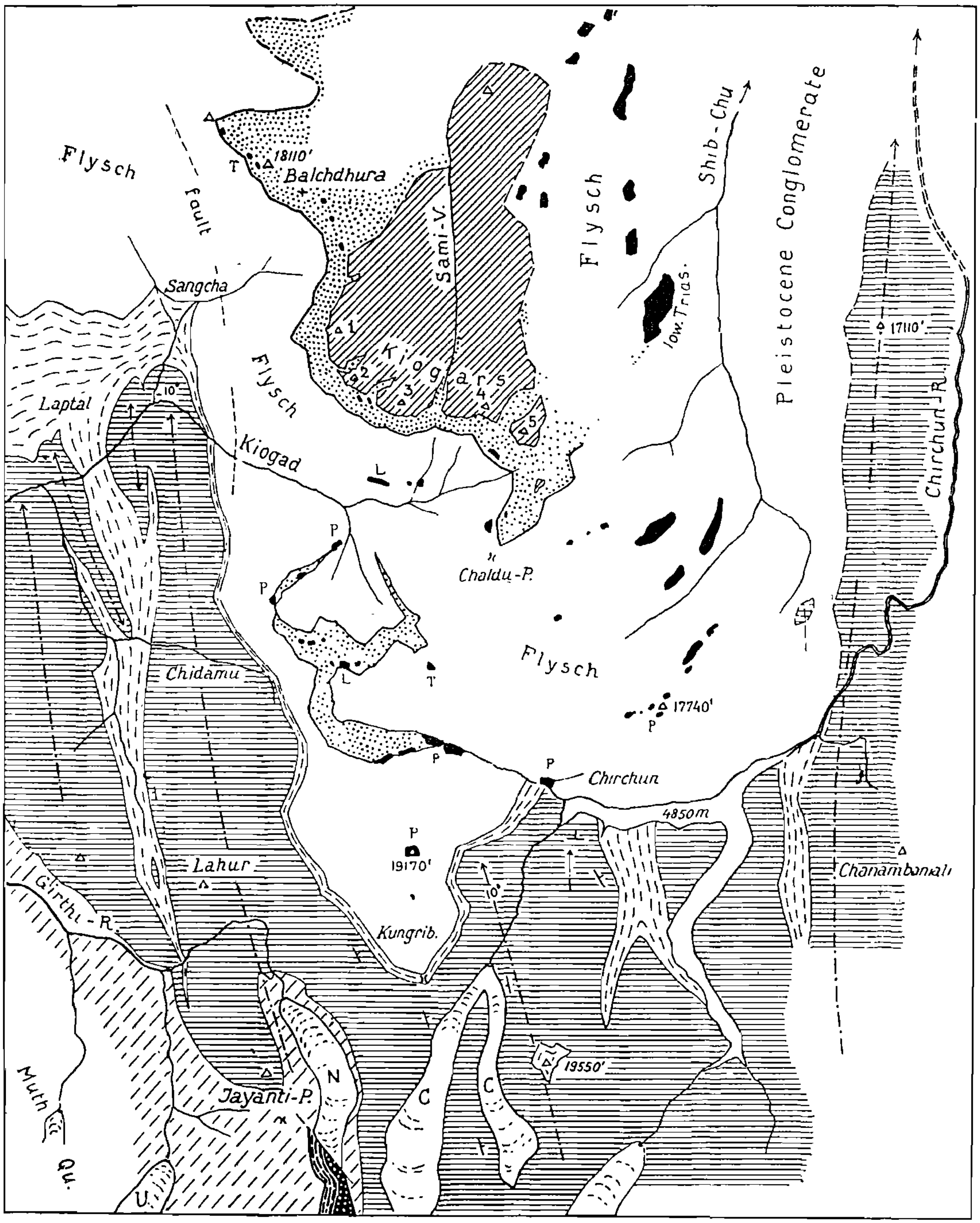


Fig. 133. Tectonical Sketch-Map of the Kiogar-Chirchun-Region. 1: 140,000, after v. Krafft and new observations.

Himal. Facies: Flysch, Cret. — Spiti Sh, Portl. — Kioto Ls., Rhät. — Kuti Sh, Noric — Low. Trias. to Silurian

Tibetan Facies. Basic Igneous, partly mixed with cherty Flysch — Kiogar Series Mesozoic — Exotic Blocks P Perm, T Trias., L Lias. — pitching anticlines

FROM THE HIMALAYA TO THE TRANSHIMALAYA (TIBET)

by A. GANSSER

Introduction

The first observations of this region are due to Captain STRACHEY (59). HENNIG (32) has described the rocks collected by SVEN HEDIN. Thus the conglomerates of the Kailas and the granite north of it were mentioned. However, almost nothing was known of the geological connections, as it seems that no geologist had ever visited sacred Kailas.

The following descriptions are the result of two rapid excursions, one of 13 days duration, from the Mangshang Pass as far as the north side of the sacred Kailas in the Transhimalaya, the other of 9 days, from the Balchdhura to the upper Sutlej. During this hurried and difficult travelling with an abundance of impressions in an almost unknown country, thorough investigations were made impossible. Great was my astonishment when I came across Flysch with exotic blocks instead of Tertiary lavas, Triassic and older formation in place of younger Tertiary, or suddenly a nicely traced counter-thrust of contorted metamorphic Flysch over the non-metamorphic horizontal Kailas conglomerate. The greatest obstacle, however, was the fact that the white man is forbidden to travel in this Tibetan country where every stone is looked upon as sacred and where geological work can only be carried out on the sly. Inspite of this, the results were better than we anticipated and may form the basis for future research.

What has been said about the region bordering on Tibet conclusively shows that the tectonical boundaries do not correspond to the political boundary between India and Tibet, formed by the watershed of Zaskar range. The Flysch zone with its exotic blocks, for instance, is of a western strike and forms an angle of 45° and more to the Tethys Himalaya. In the eastern part, after crossing the Mangshang Pass, a zone of 30 kilometers is passed which still belongs to the Tethys Himalaya, whereas more to the West the interesting "Klippen" of the Kiogars form the boundary.

The tectonical zones traversed from S to N are as follows:

The Tethys Himalaya North of the Indo-Tibetan Frontier

(Continuation of p. 167; see Pl. V, Sect. 9 b).

At the northern end of the gentle Mangshang glacier (Phot. 52, Pl. XIX) the claret-coloured crinoid shales reappear between the quartzite, forming the cores of complicated folds leaning towards SW (Fig. 134).

The thrust-folds of the red Silurian over the quartzite show at some places sharp unconformable contacts. Below the red shales are green layers, except where they have been cut off tectonically. The boundaries of the rigid quartzites and the softer Crinoid shales are sharp sliding planes, also where the series is not reversed.

More to the NE the shales and quartzites, dipping regionally towards NE, are normally overlain by Kuling shales, Chocolate shales, Kalipani limestone, and about 50 meters of black micaceous Kuti shales, which are once more thrust by Silurian quartzite and red Crinoid shales.

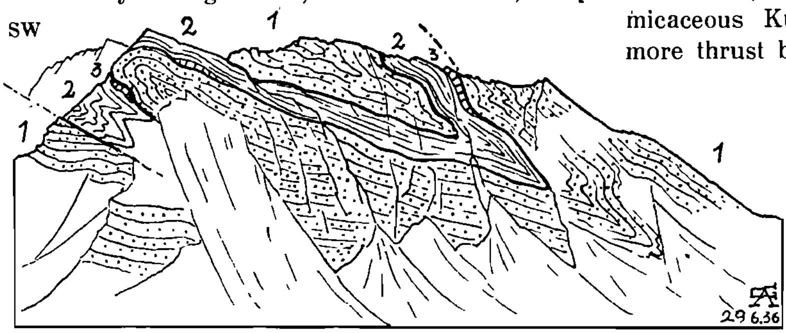


Fig. 134. Overlying Folds north of Mangshang Pass (Tibet). 1 = Brownish weathered quartzite; 2 = Reddish Crinoid shales; 3 = Green shales.

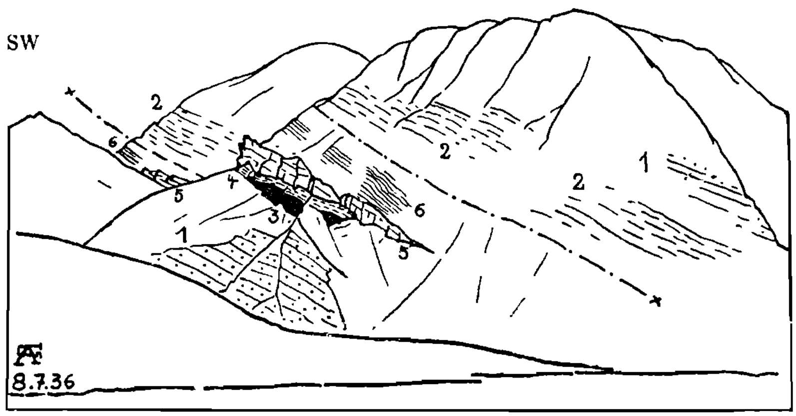


Fig. 135. The first Thrust over Triassic ENE of the Mangshang Pass. 1 = Muth quartzile; 2 = red Crinoid shales (Silurian); 3 = Productus shales; 4 = Chocolate shales; 5 = Kalapani limestone; 6 = Kuti shales.

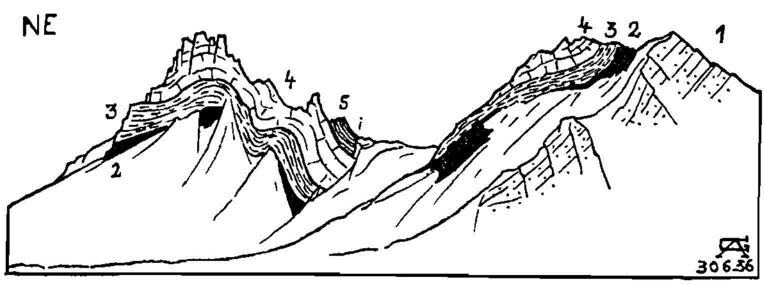


Fig. 136. The last typical Triassic of the Tethys Himalaya. 1 = Muth quartzite; 2 = Productus shales; 3 = Chocolate shales; 4 = Kalapani limestone; 5 = Kuti shales.

The mountains gradually flatten out on this Tibetan side and the outcrops are more and more scanty. Only the layers of the Kalapani limestone are well exposed, projecting out of the rounded talus-covered slopes.

Some kilometers before coming to the long flat-topped ridges of the lower Mangshang Valley, the last Mesozoic of unquestionable Himalayan facies is encountered (Fig. 136).

The strike here is SE and the dip, complicated by minor folding, towards NE. The same structure was seen from a hill at a distance of 10--15 kilometers towards south-east. Even part of the southern, above mentioned Triassic zone is visible. Similar to the region of Kuti, the thrust scales seem to be constant over long distances.

Towards north, the Mesozoic series disappears below the terraces. The gravels are partly hardened and seem to correspond to the vast Pleistocene gravel deposits of Taklakot and of the Sutlej-Valley. They form especially the top of the higher hills of the terraced landscape towards north. Fortunately, the underlying structure is exposed here and there along the Mangshang river. At first, no distinct exposures appear after the Kuti shales. But some kilometers farther, old quartzites are encountered. But we cannot say whether they overlie or underlie the former Mesozoic. Probably they are thrust again.

About 15 kilometers SW of Shinglabtsa (topographic sheet 62 B 1'' = 4 miles), limestone layers of about 50 meters thickness are once more exposed, overlain by dark clay-shales, recalling the Kuti shales. The contact of the limestone upon the quartzite is not visible. The limestone is subdivided into a lower part of brown weathering and an upper well-bedded and clearer one with lumachelle layers of Brachiopods and Crinoid fragments. From the lower part were gathered fossils recalling Paleozoic corals (Devonian?). The basis of the limestone is not exposed.

In the overlying black shales no fossils were found, as time was too short for research. They are overlain by Pleistocene gravels which are no longer horizontal, but dip distinctly some degrees towards north.

Two kilometers farther north-east, the black shales are overlain by a new series of more or less micaceous and argillaceous grayish sandstones of brownish to yellowish weathering. It seems that this intensely folded series overlies the shales unconformably, and is also overlain unconformably by limestone layers. The sandstones contain indistinct plant remains and may have a total thickness of one kilometer (Fig. 137).

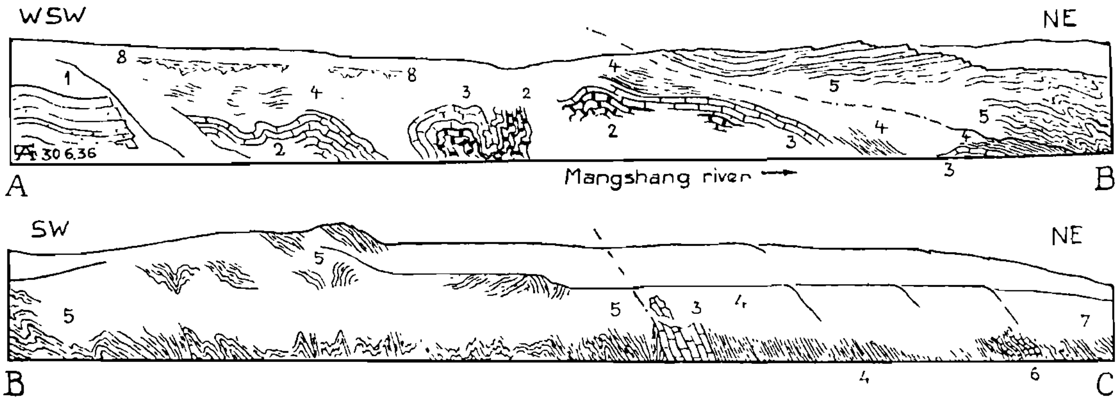


Fig. 137. Detail of Structure along the Mangshang River.
1 = Quartzite, Paleozoic; 2 = Brown weathered limestone with corals (Devonian?); 3 = White limestone with Brachiopod- and Crinoid breccia; 4 = Black slate, partly micaceous; 5 = Micaceous, slaty sandstone of brown weathering; 6 = Brownish-gray sandy limestone with Belemnopsis (Dogger); 7 = Black slates, probably Spiti shales; 8 = Pleistocene conglomerate.

Above the sandy series follows a well-bedded limestone of 50—100 meters which projects out of the badly exposed region over a long distance in the shape of a crest. The dip is 60° to NE. The character of the limestone recalls that of the series found farther south below the black shales. The more brownish basal limestones do not occur here.

The limestone is normally overlain by black shales of Spiti-like facies, of over one kilometer thickness. Along the Mangshang river they form continuous outcrops within this flat gravel country.

The shales dipping constantly 50—60° to NE pass 1,5 kilometers farther north-east on to dark brown sandy limestones of more than 100 meters, with locally interbedded shales. The intimate stratigraphic connection is all the more important as some limestone layers are full of Belemnites, some of a thickness of 2 centimeters and a length of 20 centimeters. Size and shape point to *Belemnites (Belemnopsis) canaliculatus* of Middle Jurassic age (Dogger). The somewhat sandy layers with indistinct carbonaceous plant remains recall the flysch-like series mentioned above. The facies seems to correspond to that of Tsang and Ü in Tibet, north of Kangchenjunga, described by HAYDEN in 1907 (23). However, indications of

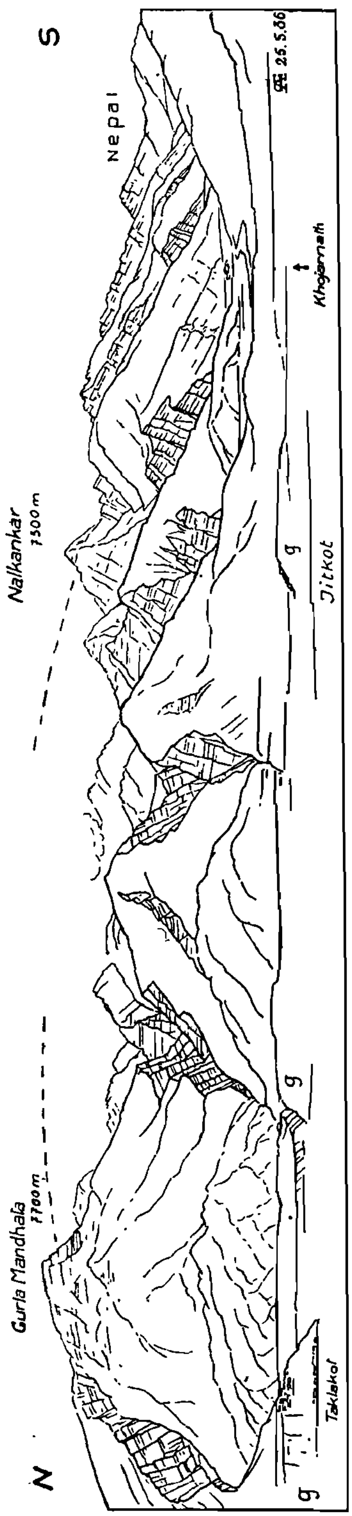


Fig. 138. The anticlinal Structure of Gurla Mandhata seen from West.
g = Pleistocene gravel terraces.

the thickness of the formations and a scale to HAYDEN's sections would be needed for a better comparison of the two Tibetan regions.

The normally overlying strata are again mainly black shales. They seem gradually to develop from the underlying sandy and argillaceous limestones, and recall the Spiti Shales. They were followed almost continuously as far as Shinglabtsa. The large river which is the main source of the Humla-Karnali river of Purang and Nepal, has completely cut its way into the black crumbling shales. Some typical flint concretions were found, but without fossils. Nevertheless, the general character points to Spiti shales of Upper Jurassic age. Thus the Middle and Upper Jurassic would be largely represented.

The Tectonical Position of Gurla Mandhata

This huge Tibetan mountain (7700 meters) as seen from Shinglabtsa, is unique. Clearer than ever before, the anticlinal arch appears at this place which is in the direction of the axis. Inspite of this, on account of the axial pitch towards west, the vast anticline has already disappeared in the region of Shinglabtsa.

On the geological map of the Himalaya 1″: 50 miles (8, 1934), Gurla Mandhata is indicated as "unclassified gneiss". This may be more or less correct. LONGSTAFF who in 1907 tried to climb the mountain seems to have paid no attention to geology. The first time we went off the main track to Purang, the writer could study the mountain at a short distance. The pebbles found in the gorges are metamorphic phyllites, partly also muscovite-biotite gneiss. The latter seem to form the core. The Pleistocene terrace gravels, south of Taklakot, contain also abundantly biotite-muscovite gneiss, of the Darjeeling type, though probably coming from the south. We know by courtesy of Dr. H. TICHY of Vienna, who climbed the Gurla in May 1936 up to 7200 meters on the west side, that the main rock is a metamorphic phyllite. On account of the axial pitch only these upper strata of the anticline are encountered on the western slope. The anticlinal structure is easily recognized by the distinct schistosity (Fig. 138).

The highest summit of Gurla Mandhata already belongs to the northern limb of the anticline. The southern limb forms the Nalkankar 7300 meters on the border of Tibet and Nepal, and continues far into Nepal. The culmination is between Gurla and Nalkankar. The western pitch of the anticline is recognized in Fig. 138, producing the domelike shape of the whole group. The width of the Gurla anticline, south of Lake Manasarovar, is 30 kilometers or more.

Considered as a whole, the Gurla anticline with its freshly eroded ravines gives the impression of a morphologically and tectonically young structure. According to the topographic maps the anticline continues from the Gurla summit towards east, but possibly also pitches in that direction.

The Mesozoic Raksas Series

North of Shinglabtsa follows a completely new series of Flysch with exotic blocks, which will be described later in order to pass on to the south shore of Lake Raksas, north of Jungbwa, where below the flysch older Mesozoic sediments reappear. They will be named Raksas series. More in the West, on the Sutlej, similar strata form the Chilamkurkur ranges and will be named Chilamkurkur series. On account of their strike towards Raksas, on the north side of the great depression of Gyanima, they will be dealt with together, although the facies is not altogether alike.

1. The Section of Raksas Lake (Pl. V)

North of Jungbwa black slates appear at a southern dip of 30—40° below the Flysch. They strikingly resemble the corresponding slates of Shinglabtsa, which were regarded as Spiti shales, and this inspite of a region of 20—25 kilometers between where they are covered. The thickness cannot be determined accurately as their basal part is covered with the alluvial deposits of the plain of Jungbwa. About 200 meters or more are exposed.

Only 2 kilometers north of Jungbwa another isolated outcrop is encountered. It already belongs to the lower part of the Spiti-like series. The phyllitic greenish-gray clayslates dip 40° to SSE and may attain a thickness of 100 meters. At first sight they recall somewhat the Dalings. But a deformed impression of an ammonite, unquestionably younger than Triassic was found. After taking a cast, comparison led to the conclusion that it was probably *Polymorphites Jamesoni* Sow., which would be a middle Liassic species. As the phyllite forms the basis of the black shales of Jungbwa, the correspondance of the latter with the Spiti shales is the more probable. Indications of Dogger, similar to that of Shinglabtsa, are lacking here or at least no outcrops are exposed.

Underlying this possibly Liassic series follows towards north, without a visible contact, a large series of greenish sandy micaceous shales with irregular brown argillaceous joints. North of the Dopserma beach of Raksas Tal they are folded, but dip regularly southward again farther north.

Macroscopically the shales seem to be strongly chloritic and make a flysch-like impression. Their facies and structure recall the flysch-like sandstone series south of Shinglabtsa, all the more so, as they also underlie the Jurassic sediments below the Spiti shales. Under the microscope, the main mineral is quartz in angular grains, embedded in a reticular groundmass of fine scaly chlorite with sericite and limonite. The latter also forms small globular grains. Rarely, larger chlorite scales of green pleochroism are present too, together with epidote, rutile and zircon. No micro-fossil was observed.

On the section 9c, Pl. V the series above is designed as (f). Below it follow with a passage zone:

- e gray-brown quartzitic sandstones. Sharp conformable boundary to
- d well bedded clear blue-gray limestone with small dark knots, apparently of crinoids, 100 meters or more. Distinct foraminifera are observed under the microscope in the somewhat oolitic marmorized rock. Towards west, reddish sandy slates are interbedded, which pinch out towards east. The dip to SSW is irregular. In places the stratification is vertical.

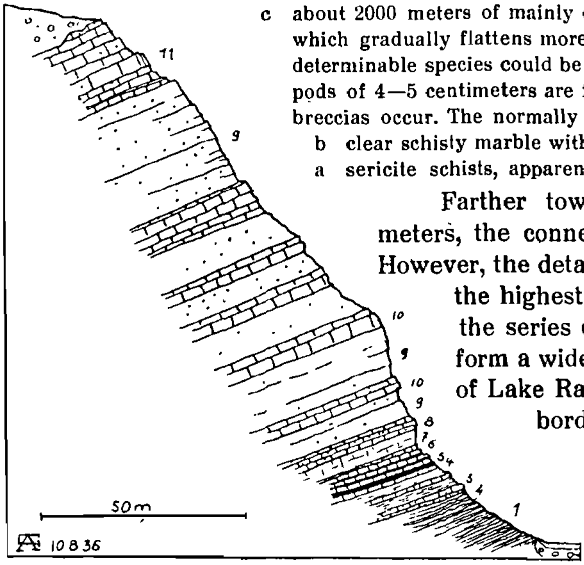


Fig. 139. The normal section of the Chilamkurkur Series SW of Chilamkurkur.
1 = black slates; 2 = dark grey slates; 3 = brown sandstone layers; 4 = dark banded limestones; 5 = red slates alternating with Nr. 4; 6 = reddish sandy limestone; 7 = limestone with *Megalodon*-like shells; 8 = brown quartzitic sandstone; 9 = yellow-brown quartzitic sandstone; 10 = dark limestone; 11 = minutely banded, somewhat sandy limestone.

c about 2000 meters of mainly dark gray limestones of a remarkably regular dip to SW which gradually flattens more in the north. Amongst the different traces of fossils no determinable species could be gathered on the rapid traverses. Spiral relics of Gastropods of 4—5 centimeters are frequently enclosed. Also lumachelle layers and Crinoid breccias occur. The normally underlying strata in the north are

b clear schisty marble with thin sericitic layers. The contact is concealed by gravel.

a sericite schists, apparently conformable to (b), exposed over 1 2 kilometers.

Farther towards west in the mountains reaching 5800 meters, the connections of the different divisions are exposed. However, the details are no more recognized. The series (c) forms the highest summits and covers in an almost flat position the series (b) and (a). The sericite schists, wavy in detail, form a wide gentle anticline, which dips on the north shore of Lake Raksas towards NNE below the wide gravel plain bordering the Transhimalaya. The composition of the fine schists varies from yellowish carbonatic sericite schists to greenish sericite-chlorite schists. They partly recall the Garbyang series. Rarely thin marble-layers are interbedded.

Similar conditions also were recognized at the distance on the eastern shore of Raksas Lake. Little is known of their age, except that they are older than Jurassic and probably older than Triassic, inasmuch as the limestone series (c) may be Triassic. Probably, the sericite schists are Paleozoic.

The Mesozoic and older formations of Raksas Lake are mapped as Eocene in (8). They occur also in the western prolongation north of the great basin of Gyanima as far as the Sutlej, including the Chilamkurkur ranges which were also designed as Eocene.

2. The Series of Chilamkurkur

The Raksas series was seen emerging from below the flysch north of Jungbwa. Similar conditions were found also in the upper region of the Shib Chu, more than 100 kilometers farther west The flysch forming the basis of the Kiogars is covered over 20—30 kilometers by conglomerates of probably Pleistocene age. Only towards the mountain ranges of Chilamkurkur the rocks in place re-appear, though already belonging to the lower Mesozoic. The relation with the flysch is visible somewhat farther north in the Shib Chu Gorge, where the flysch shales with enclosed exotic blocks are passing eastward over the Chilamkurkur series into the sky. The strike of the flysch and of the Chilamkurkur is here abnormally towards north, and only north of the Sutlej it turns towards NW.

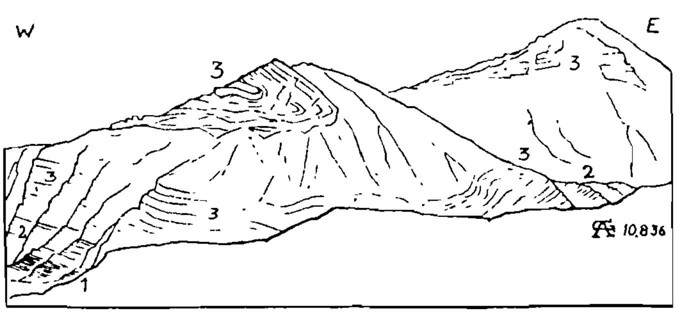


Fig. 140. The Structure of Chilamkurkur.
Black shales; 2 = lower division; 3 upper division of Chilamkurkur series.

Indisputable flysch passing over the limestones of Chilamkurkur was only found in the Shib Chu Gorge. Southwest of this range,

where a good part of the Chilamkurkur series forms continuous outcrops, the basis below the limestone-quartzite series is a slate which partly resembles flysch, partly Spiti shales, but probably is younger Paleozoic (Fig. 139).

The above section shows distinctly two main divisions: Nrs. 1—7 form the lower and Nrs. 8—11 the upper part. Unfortunately, the basis and the overlying sediments is wanting, and in no place complete sections were encountered. Also the facies seems to undergo changes over short distances, so that no accurate correlation can be made. Between the two main subdivisions indicated above, there is a layer of 3—4 meters teeming with thick white calcite shells, recalling *Megalodon* (Phot. 58, Pl. XXI). Should they be such, the whole series would have to be regarded as Triassic-Liassic. This also results from a comparison with the Raksas series, and with the Kioto limestone of the Tethys Himalaya.

At the Chilamkurkur mountain the strike changes from north and northeast to east in the more western part, and the Chilamkurkur folds become joined to the Raksas series. The local conditions are shown in Fig. 140.

Towards north follows a continuous row of folds usually of a northern strike until the Sutlej, though only the more resistent upper Chilamkurkur series is exposed. The western folds are decreasing and disappear under the flysch, which in turn is covered by terrace conglomerate or basic igneous sheets (Fig. 141 and Phot. 62, Pl. XXIII).

Continuous outcrops are only found when reaching the Sutlej, which has cut a gorge across the Chilamkurkur series. The folds are directed across the river. The bipartition is well-marked. The upper series is here also characterized by a repetition of quartzite and limestone, the lower one by well-bedded limestone with interbedded, more or less sandy slates.

Instead of the dark slates which form the basis of the Chilamkurkur series, we found on the Sutlej calcareous slates of more than 100 meters, which resembles the Alpine "Bündnerschiefer". They are partly sandy, similar to the sandstones south of Shinglabtsa and north of Jungbwa (series f). Also, the basis of the calcareous slates is exposed in the shape of black slates. Both series are minutely folded, and penetrated by quartz veins. The facies recalls the flysch, although the tectonical and stratigraphical position points to an older age.

A comparison with the occurrences of Raksas Tal suggests a reversed position of the Chilamkurkur series on the Sutlej. The limestones of Chilamkurkur might correspond to the series b, c and d, and the calcareous slates to the series f, partly also to the Liassic (?) phyllites, and the black shales to the Spiti. This, however, is very uncertain. More probably, the large mass of calcareous slates corresponds to the lowest part of the Chilamkurkur series, though the facies is altered and the thickness increased. Lower strata than the black slates are not exposed on the Sutlej as far as could be seen.

Attention may further be drawn to some morphological features.

Three different older courses of the Sutlej may be recognized, which are still preserved in relics above each other. On Fig. 142 A an old wide valley bottom is seen (a), into which the river has enforced a new gorge. This points to a young uplift of the Chilamkurkur ranges. A third phase is indicated by a terrace within the gorge, about 20 meters above the

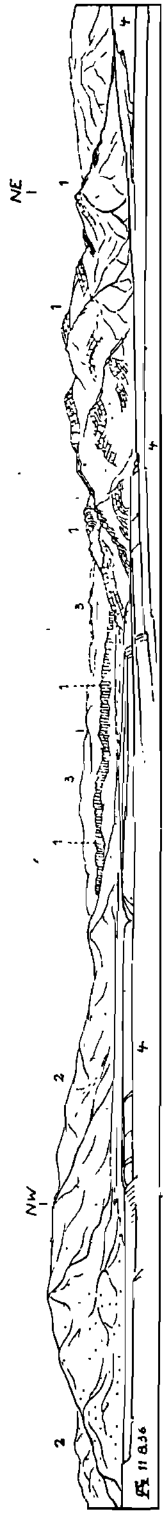


Fig. 141. Panoramic View of the Chilamkurkur Ranges and the Peridotitic Sheet seen from the Gravel Terrace of the Shib-Chu.
1 = upper Chilamkurkur series; 2 — peridotitic sheet overlying the flysch; 3 = the probably crystalline rocks of Transhimalaya; 4 = Pleistocene conglomerate.

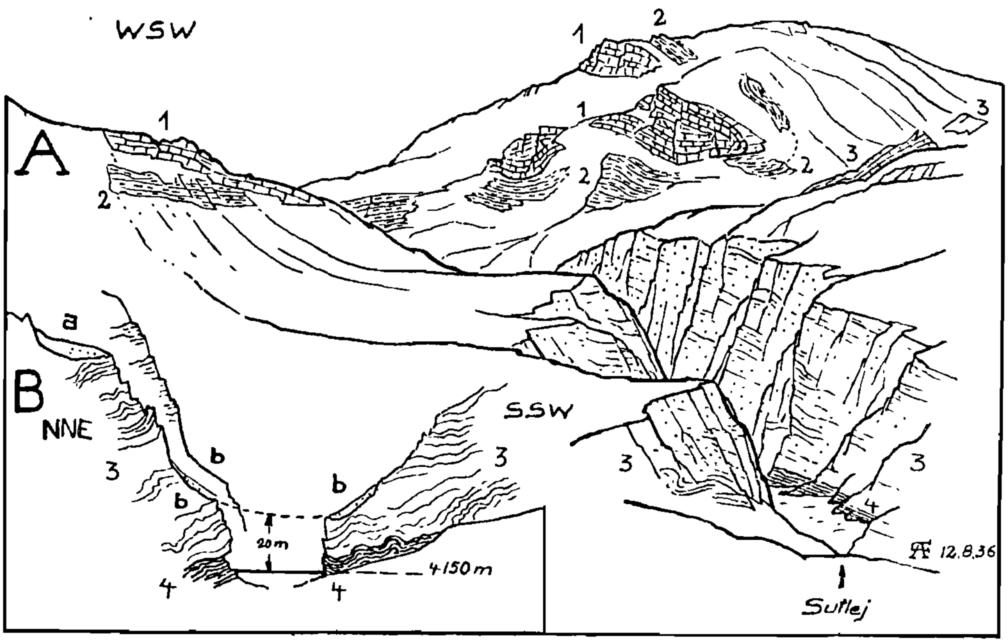


Fig. 142 A and B. The Sutlej-Gorge across the Chilamkurkur Series.
1 = Upper Chilamkurkur series; 2 = lower Chilamkurkur series; 3 = calcareous schists, partly sandy; 4 = black slates.

present valley bottom (b in Fig. 142 B). Finally, the river has once more renewed its force and formed a gorge within the gorge, with overhanging walls. At the end of the chapter on Tibet, the connection with the great lakes will be discussed.

The farther continuation of the Chilamkurkur series towards NW was seen from a high point of about 4750 meters, or 600 meters above the Sutlej, wherefrom towards west, the whole Sutlej depression is overlooked (Fig. 143).

From the point mentioned above, the hard layers (limestone) of the Chilamkurkur series could be recognized, showing a southern dip over a distance of at least 60 kilometers. At some distance beyond the gorge through the Chilamkurkur series follow in a huge extension the conglomeratic gravel terraces, into which the Sutlej and its tributaries have cut a gorge of 100—200 meters depth. The gravels are usually well cemented. It seems to be that region mentioned by STRACHEY (59) as containing fossil mammal bones. The locality is not indicated, but must be somewhere north of the Niti Pass. The mammals point to Pleistocene. By analogy,

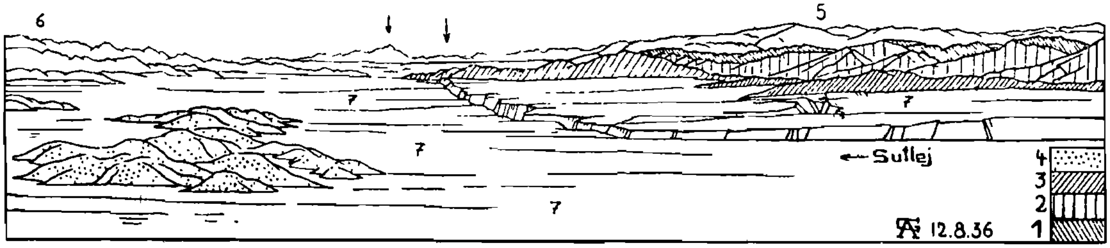


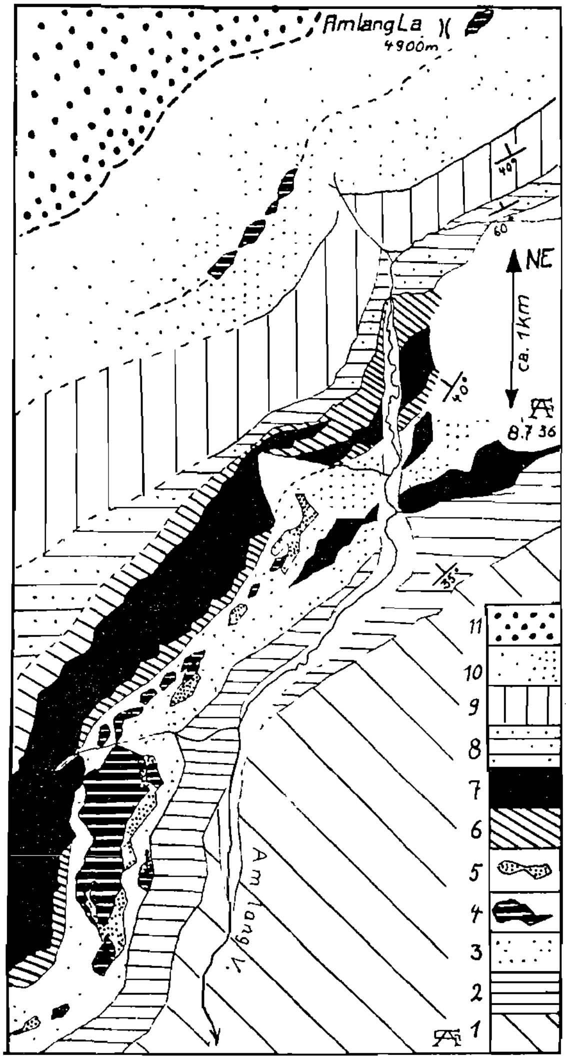
Fig. 143. Panoramic View of the Sutlej Depression, seen towards NW.
1 = Basal calcareous slates of the Chilamkurkur series; 2 = upper Chilamkurkur series; 3 Flysch; 4 = Young peridotite; 5 = zone SW of Gartok, probably crystalline; 6 - the sedimentary formations of the Tethys Himalaya; 7 = horizontal Pleistocene conglomerate.

we accept the same age also for the corresponding conglomerate of the Shib Chu and of Taklakot in Purang (Phot. 63, Pl. XXIII).

The extension of the peridotitic Tertiary eruptive sheets could also be followed from the view point. They project like islands over the horizontal terrace conglomerates, until they are lost of sight towards west.

The Flysch Regions with Exotic Blocks in Tibet

In the preceding chapter we mentioned the great mass of flysch with exotic blocks of Shinglabtsa, which covers the Spiti-like shales. When the writer discovered the exotic rocks of Amlang-La (Tibet) in June 1936, he only knew the phenomenon of exotic blocks on the Himalayan border from literature, and it was but in August when he visited the classic region of Malla Johar. The exotic blocks appeared in such a striking way at Amlang-La, that the similarity was recognized at once.



1 = sandy well-bedded flysch shale, partly siliceous;
2 = greenish siliceous slate, well-bedded; lower series;
3 = zone of glauconitic sandstone, more or less quartzitic, or white and arkose-like, partly with radiolarians;
4 = exotic blocks; in the lower part red brecciated limestone with corals and ammonites of Lower Triassic; in the upper part white to yellowish dolomitic limestone
5 = igneous rocks, more or less tuffaceous, of andesitic magma, older than flysch, but younger than the blocks, though intimately connected with the latter;
6 = upper Cretaceous limestone connected with flysch;
7 = gabbroid rock younger than flysch;
8 = siliceous, usually reddish and green beds;
9 = yellowish white sandstone;
10 = sandy shales together with the upper exotic blocks;
11 = young peridotitic rock.

Fig. 144. Sketch-map of the Exotic Region South of Amlang-La.

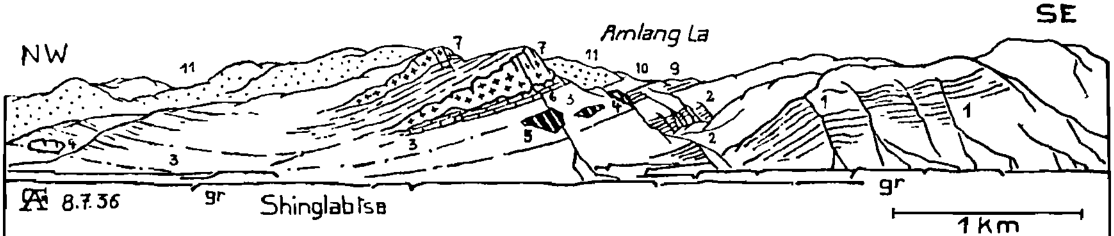


Fig. 145. View of Amlang-La Region

The main purpose of the second excursion into Tibet was to find the northern continuation of the exotic region of Malla Johar.

1. The Flysch with Exotic Blocks of Amlang-La

When traversing the hills of the lower Mangshang Valley towards Shinglabtsa, the northern part of the uppermost Humla-Karnali Valley presents a striking aspect: bright blocks up to one kilometer in length are embedded within dark reddish to greenish rocks. Smaller isolated blocks are encountered over a distance of almost 20 kilometers towards west. Towards north, they follow the valley up towards Amlang-La (Pass nearly 5000 meters), where the best exposures are found. Towards east, the blocks partly strike into the air.

Unfortunately, geological observations could only be made in a hurry "en passant", whereas much time would be needed for a thorough study. The present remarks are confined to excellent outcrops in the valley between Shinglabtsa and Amlang-La (Fig. 144, 145).

In a former chapter we have pointed out the existence of a normal south-eastern strike of the Spiti shales. The overlying flysch strikes nearly at a right angle to them, towards E and NE. The change in the strike may be sudden. The gravels cover the contact.

a) The Flysch

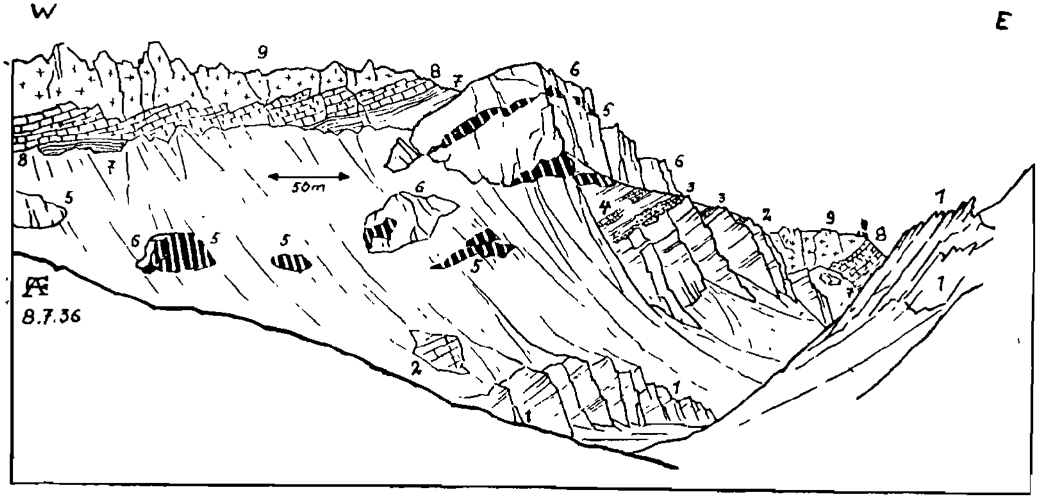
The flysch series begins with sandy shales (facies of Giumal sandstone?), with several layers of greenish well-bedded siliceous shales. The visible part of this series overlying the Spiti is about 300 meters thick. Above it follow more or less argillaceous siliceous shales or slaty chert. They are usually green and well-bedded in layers of 10—20 centimeters. The thickness, as far as it is exposed, is 100 meters at least. Under the microscope, the groundmass is found to be a hornstone-like quartz with abundant though badly formed minerals like zoisite. The darker siliceous shales (2), also with reddish layers, are 50—100 meters thick, and contain green quartzitic glauconite-sandstone in the middle part.

Under the microscope the coarser variety shows angular quartz, green and blue-green roundish glauconite grains, usually together with a limonitic substance. The accessories: microcline, orthoclase and acid plagioclase are the components of an arkose-sandstone. The occurence of small fragments containing an ophitic mixture of small plagioclase laths is important. They derive from medium basic lavas, and recall the igneous rocks connected with the exotic blocks.

A finer grained sandstone, of the same series, carries beside the above named minerals also some carbonate grains, titanite and leucoxene. Again the debris of basic rocks occur. By their relictic igneous content these sandstones recall somewhat the famous Taveyannaz-sandstone of the Alps.

The series of green siliceous shales and sandstones are overlain with a sharp contact by a few meters of a dark red argillaceous. It is glauconite sandstone with radiolarians. The red colour derives from the abundant limonitized hematite. The rock is mainly composed of angular quartz and glauconite with some plagioclase. The numerous radiolarians (Spumellarians) were unexpected. Their interior is usually filled with limonitic substance. Also some foraminifera are present, like *Patellina* (?). The overlying strata are calcareous, gray to brownish-yellow sandstones (c) of which only a few meters are exposed. However, they seem to pass into

d) the middle part of the flysch, which also is sandy, containing igneous fragments. This complex series (d) is characterized by the exotic blocks (see Fig. 146 and Phot. 64, Pl. XXIII)



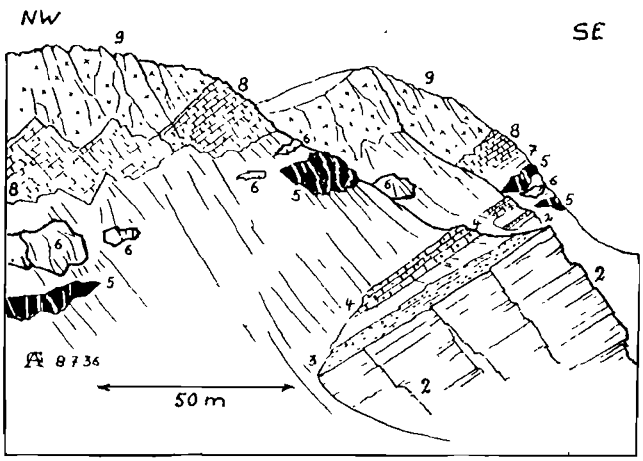


Fig. 146 A and B. The Exotic Blocks South of Amlang-La.
1 = sandy, siliceous flysch;
2 = green siliceous shale with glauconite sandstone;
3 = red glauconite sandstone with radiolarians;
4 = calcareous and argillaceous sandstone, gray brown;
5 = porphyritic eruptive rock enclosed in the flysch;
6 = exotic blocks, red and white, of lower Triassic;
7 = sandy to shaly, black to brown flysch;
8 = finely stratified limestone with miliolids (Upper Cretaceous);
9 = syeno-diorite, younger than flysch.

The middle part of the flysch, the exotic blocks of wich stand out very clearly, is itself badly exposed. It is mainly a sandy, argillaceous brown to black slate.

The overlying flysch series is made of well-bedded limestone of 50 meters and more, with calcite veins. Under the microscope the rock appears somewhat oolitic. The lime is coarse-grained, and the finer structure is obliterated. The main micro-organisms seem to be *Miliolinidae* and *Textularidae.*

The limestone layers are unconformably cut off by syeno diorite, and also partly pierced by such. They will be described later on.

In the background of the valley towards Amlang-La, three intrusive syeno-diorite sheets are traversed, which have broken across the whole flysch series. Upon the limestones which locally are intensely folded, green siliceous shales follow again. They are locally vertical, but usually dip again 60° to NW. Upon them are bright sandstones, usually yellowish white, 200—400 meters thick, though badly exposed. On the Amlang Pass further follow dark sandy-argillaceous flysch slates of varied composition, containing again exotic blocks. They are much less abundant than at Shinglabtsa. Also the joined basic igneous rocks are less frequent. These blocks of the higher flysch series are different from those of the lower zone.

b) The Exotic Blocks

α) Upper Series: West of Amlang-La, exotic blocks are confined to a distinct flysch horizon. Three blocks or more are distinguished at a distance by their white colour contrasting with the lower red ones. Also a few meters east of Amlang-La a single block projects out of the flysch slate, devoid of igneous material. It is about 80 cubic meters in size and composed of witish brittle dense limestone. It contains some dolomitic layers of a few centimeters each. No fosssils were found. Towards the contact the flysch is crumpled. Probably, also the other three blocks on the same level west of Amlang-La are composed of the same limestone. There may also be basic rocks connected with them.

β) Lower Series: The single blocks become very large. The pretty block at the right lower issue of the Amlang-Valley is about one kilometer long and nearly 200 meters thick (Fig. 147). Like the other frequent blocks, it arrests attention by its white and red colour. They immediately recall the Hallstadt facies encountered in the Kiogar region. The minutely marblized rock is traversed by red earthy lime. Where the dense red limestone is preserved, it is rich in Ammonites, while the earthy parts composed of white angular debris, are probably syngenetic breccias.

The ammonites which occur only in the red layers, are filled with snow-white coarse calcite and thus are at once recognized. However, this calcitisation makes it difficult to collect determinable specimens. Also the breccia contains ammonites, though only in their red matrix, while the finely marbled pink to white components are devoid of fossils. Clay fragments too are contained in the breccia.

Professor Jeannet determined some specimens belonging exclusively to the Lower Triassic *Paraceratides,* a Muschelkalk species. Another form recalls *Ophiceras*, which would point even to Eotrias. Also the suture-lines of the species in situ, which could not be extracted, points to Lower Triassic forms.

Besides the ammonites, frequent coral colonies are found, up to several cubic meters. The single branches are 1—2 centimeters in diameter and usually show 6 main partitions.

About 13 blocks of the lower flysch were counted, all of the same facies, different from the upper series. This is of importance when compared with Malla Johar, where also two series are distinguished. The upper blocks recall those of the Kiogars, the lower ones those of Chirchun.

c) The Older Igneous Rocks connected with the Blocks

At first sight the exotic blocks seem to be enclosed in a wild mixture of flysch and igneous rocks. The flysch being of a similar dark colour, close investigations are needed to distinguish it from the igneous rocks. At Amlang-La, the position is clearer than at the Kiogars: the igneous rocks are blocks in the flysch similar to the limestone and connected with it, although of younger age thau Triassic. Especially the huge block in the lower Amlang Valley (Fig. 144) shows how the igneous penetrated into the limestone, so that the igneous rock forms part of the limestone block seen at a long distance. The distinct contact metamorphism (marginal assimilation of carbonate) too are conclusive for the post-Triassic age of the intrusion.

The igneous rock is not only part of the limestone, it may also form separate blocks in the flysch. Though the igneous rock may be enclosed in the limestone, it never is found in dykes or sills penetrating the flysch. Some igneous blocks in the flysch contain small fragments of limestone. The flysch sandstone, however, contains small fragments of similar igneous rocks.

Thus, the igneous rocks connected with the exotic blocks are younger than the limestone blocks, but older than the flysch. This is the preliminary result in the Amlang-La region.

The petrological study of an isolated igneous block (about 200 meters to the left of the largest one in Fig. 146) had the following result: The dark massive rock shows under the microscope an altered groundmass of fine plagioclase laths, amongst which seems to be also some orthoclase and quartz. The plagioclase judged by its small angle of extinction, is an oligoclase-andesine. Of special interest are larger tricline phenocrysts of alkalifeldspar of an optical axial angle 2 V – 82° (determined on the Fedorow-stage). They are indistinctly albitised and also show calcite segregation. Quartz phenocrysts are subordinate. Their edge and cracks are limonitic. The whole rock is rich in hematite scales. The original rock seems to be a quartz-porphyrite.

Other darker and denser types give the impression of being basalt. According to the mineral contents, it is however a more acid rock. Macroscopically, small calcite vesicles are recognized. The rock is an amygdaloid porphyrite with segregated calcite, and is mainly composed of a fine entanglement of andesine laths. The large basic plagioclase is almost entirely transformed to calcite. The original vesicles are filled with calcite, with which may be associated a greenish chlorite, and some marginal sericite. Over the whole slice magnetite and leucoxene are spread, enriched around the calcite vesicles. The plagioclase laths are devoid of ore inclusions. Other dark minerals are not present.

A similar amygdaloid porphyrite is still more altered, the plagioclase being almost unrecognizable. The calcite vesicles are irregular. Chlorite and ore are more abundant, but not concentrated towards the visicles.

A more acid type associated with a Triassic block is to be designed as a quartz porphyrite. The massive rock is purple and shows under the microscope also a fine entanglement of plagioclase laths. In this groundmass appear some altered feldspar phenocrysts (apparently alkalifeldspar) besides rather large quartz. Ore and sericite are finely distributed.

Besides these massive homogenous types also tuffaceous rocks are frequent, forming separate rocks, or connected with the limestone blocks in the flysch. Macroscopically, they are usually violet to red with green inclusions, or entirely green. All passages are found of a slightly tuffaceous rock to an extremely breccious tuff.

A slightly tuffaceous quartz-porphyrite, macroscopically massive, shows under the microscope fractures of feldspars. In the groundmass of fine plagioclase laths are also embedded roundish relics of rocks with other plagioclases of somewhat larger size.

Other types permit to recognize the tuffaceous character at once. A green rock shows under the microscope greenish components of an amygdaloid porphyrite embedded in a groundmass of entangled plagioclase laths of also porphyritic origin. Some inclusions contain an almost isotropic greenish chlorite. Calcite is abundant all over, forming the vesicles, and the fine grains of the ground-mass. The components being of the same type as the groundmass, the rock must be a green porphyrite tuff.

Further tuffaceous types are usually claret-coloured and green. The red groundmass may contain green enclosures. Under the microscope, the enclosures are determined as amygdaloid porphyrite, while the red limonitized groundmass is made of altered plagioclase. Amongst the enclosures are some with distinct plagioclase laths, as well as others which do not show any more recognizable plagioclase.

Finer grained types do not permit to distinguish macroscopically the red groundmass from the green enclosures. But the microscopic aspect is again the same.

An extreme tuffaceous rock resembles almost a flysch sandstone. The components of the red conglomeratic rock are not much cemented, but connected with massive porphyrite forming a block in the flysch. The composition is completely effusive, the round fragments being a red amygdaloid porphyrite. The fillings of the vesicles are partly chalcedony-like quartz. Also

large fragments of alkalifeldspar phenocrysts are present. The rock is a conglomeratic porphyrite-tuff.

d) The Young Syeno-Diorite South of Amlang-La

The figures 146 A and B and Phot. 64, Pl. XXIII show the upper Flysch limestone cut off by the younger igneous rocks. The latter form a sheet of several hundred meters thickness, and are mainly intercalated in the flysch-limestone which is completely pierced north of Amlang-La. There, the same igneous rocks occur also in the dark flysch enclosing the exotic blocks.

The massive rocks which look rather dark in the distance, are of different grain. The coarse-grained rock shows macroscopically a groundmass rich in feldspar, with indistinct stalks of augite phenocrysts. The feldspars show partly a brilliant cleavage. The finer-grained types are rather rich in dark minerals, whereas the feldspar forms a fine whitish-green groundmass in which only biotite appears, while the augite is indistinct. According to the following mineralogical and chemical composition, the rock is a biotite-pigeonite-syeno-diorite.

A fine-grained type reveals the following minerals under the microscope:

The groundmass is composed of lath-shaped altered andesine, recognized by the extinction of its twin-lamellae. A perthitic alkalifeldspar is more subordinate. The biotite forms rather large scales and is intensely pleochroitic: bright yellow to dark red-brown. Usually it is already altered, partly red-brown, partly yellowish-green, and as an intermediate mineral between biotite and chlorite no longer of distinct pleochroïsm. Partly, ilmenite was formed out of biotite, with well-marked lamellae in a mass of leucoxene (Phot. 86, Pl. XXVI). Moreover the biotite passes on directly to chlorite. A slightly pink to violet augite is particularly frequent. The angle of the optical axis measured directly is $2\,V+ = 32°$. The plane of the optical axis is parallel to (010). The extinction angle Z/c is 45°—48°. The single individuals are slightly pleochroitic from pink to violet. Besides the pinkish augite there are also types of a greenish and greenish-blue colour. The border of the large phenocrysts is usually greenish-blue, while the core is violet to pink. The greenish parts are of lesser birefringence and of a larger extinction-angle. The above data point to pigeonite. The accessories are apatite, titanite and some large grains of magnetite. The texture is somewhat ophitic on account of the massive entanglement of the plagioclase.

The coarser individuals carry more pigeonite and less biotite. The laths of plagioclase are distinct and often form idiomorphic crystals enclosed in the augite (Phot. 84, Pl. XXVI). The biotite forming large individuals is frequently completely altered to a yellowish green chlorite of a rather high refringence, composed of small scales. There are also altered, rather large, intensely perthitic alkalifeldspars. The ilmenite formed of biotite and associated with leucoxene is arranged sagenite-like (Phot. 83, Pl. XXVI). Magnetite occurs in rather large, net-like grains.

The coarsest syeno-diorite encountered shows pigeonite crystals over 1 centimeter in length, and feldspars of 1—2 centimeters with distinct brilliant cleavage pointing to alkalifeldspar. Large andesine with distinct twin-lamellae and a border of strongly perthitic alkalifeldspar (Phot. 85, Pl. XXVI) are determined under the microscope. Usually, the plagioclase is entirely enclosed in perthite. Unfortunately the alkalifeldspar is not exactly determinable. The refringence is low. The optical axial angle measured conoscopically is positive, though negative with the Fedorow stage, a common fact in perthite. The pigeonite is distinctly idiomorphic and frequently forms enclosures in the large feldspars, just the contrary to the fine-grained variety. In this coarse rock too it is zonar, with a greenish border and a

purple core (Phot. 85). The biotite is almost entirely chloritized and less abundant than pigeonite.

In conclusion, an alteration in the mineral composition, according to the size of the grain, is established.

Fine-grained: Much biotite, pigeonite. Plagioclase abundant, alkalifeldspar scarce.

Middle-grained: Biotite and pigeonite of similar importance or pigeonite prevailing. Alkalifeldspars fairly frequent.

Coarse-grained: Pigeonite and biotite subordinate (the latter may even be lacking). Alkalifeldspar frequent, usually bordering andesine.

A specimen of the middle-grained type showed the following chemical composition (Analyst Prof. J. JAKOB):

Syeno-Diorite		NIGGLI values		Beringitic magma
SiO_2	50.20	si	127	125
Al_2O_3	13.53	al	20.5	23.5
Fe_2O_3	2.78	fm	42.5	39
FeO	7.64	c	22.5	22.5
MgO	5.54	alk	14.5	15
MnO	0.12	k	0.14	0.25
CaO	8.30	mg	0.49	0.45
Na_2O	5.14			
K_2O	1.22			
TiO_2	2.56			
P_2O_5	0.42			
H_2O+	2.31			
H_2O-	0 42			
	100.18			

This composition thus corresponds to the Beringitic type, except for a little lower al- and k values of the Tibetan specimen.

The age of this syeno-diorite must be younger than the flysch which it crosses and which is considered as Upper Cretaceous. The contact metamorphism is reduced to a fine-grained border of the syeno-diorite and a slight marbling of the flysch-limestone. Perhaps the intrusion is Eocene and a pre-phase of the probably still younger peridotite described below.

2. The Peridotitic Intrusions South of Jungbwa

Wandering northward over the Amlang-La and leaving the exotic blocks behind, we find the landscape suddenly changing. We come into dark hills which show no longer any structure, and where the mountains and valleys are all alike. The floors of the meandering streams are covered with vegetation, and here and there shrubs are also visible on the bare hills. This is the landscape of the peridotite.

Coming from Amlang-La, the peridotite is seen overlying the uppermost flysch layers and extending over a large surface. The western-most occurrences were already mentioned by STRACHEY (59). From the northern foot hills of Gurla Mandhata the mighty sheet continues to the south side of the great lakes, thence to the north side of Amlang-La and towards the wide basin of Gyanima. It reappears on the Shib Chu, west of the Chilamkurkur, and thence can be followed to the gravel plain of the Sutlej (Fig. 141, 150). From Gurla Mandhata the distance is 150 kilometers; the average width of this little interrupted zone is 20—30 kilometers.

First of all we shall deal with the region between Amlang-La and Jungbwa.

The composition of the rocks is relatively simple. Only the degree of alteration (serpentinisation) gives a false impression of certain varieties. The locally different rate of serpentinisation in such a vast area is striking: The serpentine appears in whatever regions within

the less altered basic rocks, without showing any relations to structure. Possibly the serpentinisation is locally caused by hydrothermal influences.

A primary variety is found about 10 kilometers SW of Jungbwa, although it only concerns the relative importance of augite and the frequent olivine.

The fracture of the fresh heavy massive rock is yellowish to olive or brown showing the quartz-like luster of the olivine. Some black or dark olive coloured augite also appears, usually smaller than 1 centimeter. The weathered crust, of a few millimeters only, is yellowish to orange.

Under the microscope we recognize fresh *olivine* almost without any serpentinisation. It is bi-axial, positive, with a large optical angle of nearly 90° and therefore *forsterite*, which is frequent in peridotite. Most olivine crystals show a distinct wide, somewhat *undulatory polysynthetic banding*, which is about parallel to the direction of extinction X, and vertical to the predominant though indistinct cleavage (010, Phot. 71, Pl. XXIV). The lamellae may be the result of tectonical influence.

Together with the olivine, but less abundant, is a rhombic *augite*. This *orth-augite* is characterized by straight extinction and a low birefringence. The angle of the optical axis is about 90°. The axial plane is parallel to (010). These data point to *enstatite* approaching *hypersthene*. The mineral being colourless, it is better to place it with the enstatite. It is also characterized by fine lamellar inclusions, specially visible in sections parallel to c (Phot. 72, Pl. XXIV). The inclusions which are of the same orientation as the enstatite extinguish at an angle Z/c = 42—45°. The birefringence compared with that of the enstatite is much higher, and this points to *monocline augite*, formed of rhombic augite, which latter always predominates. In the more basal sections the inclusions are drop-like (Phot. 73, Pl. XXIV). In that case, two kinds may be observed belonging to augite individuals of different optical position as seen by the different extinction (Phot. 74, Pl. XXIV). Besides the fine lamellae the *ordinary augite* also occurs in isolated grains, with an extinction angle of Z/c 45°. It is colourless and homogeneous, containing no orth-augite. The frequent lamella-structure, however, indicates *diallague*. As an accessory we find *spinell* which because of its leather-brown colour and the following analysis points to a Fe-Mg-spinell with traces of Cr, as *Picotite*.

The rock is an *enstatite-peridotite* or *harzburgite*, rich in Olivine.

The chemical analysis is as follows (Analyst Prof. J. JAKOB):

Enstatite-Peridotite		NIGGLI values		Normal Peridotitic magma
SiO_2	44.08	si	59	60
Al_2O_3	0.87	al	1	5
Cr_2O_3	0.37	fm	96	90
Fe_2O_3	4 35	c	2	4
FeO	4.56	alk	1	1
MgO	43.46	k	0.12	- -
MnO	0.13	mg	0.9	high
CaO	1.24			
Na_2O	0.75			
K_2O	0.16			
H_2O+	0.20	Magma type = Peridotitic		
H_2O-				
	100,17			

Besides these completely fresh rocks, more or less serpentinized rocks are frequent. They show the typical mesh-structure of the olivine, with *antigorite* formed on the cracks. Curiously enough, this serpentinized olivine shows no longer any lamellae.

The different slices make it possible to follow the transition from the fresh olivine to the pure antigorite with a relictic mesh-structure. Where the alteration has increased, magnetitic ore has been segregated on the border of the olivine.

The augite is subject to a similar, though less intense alteration. Nontheless the relics of augite are still recognized even in a rock devoid of olivine, whether it was common augite or orth-augite.

Macroscopically the alteration is recognized by an intensely dark colouring of the rock, with a rusty surface. The specific gravity diminishes. The lustre of the augite is striking and would point to diallague amongst the ordinary augite and to bronzite in the case of orth-augite. With an increase of alteration follows a dark green serpentine with sparkling augite relics.

According to the coarse-grained character of the augite and the olivine, the peridotite must have been intrusive, not extrusive. Typical flow-structure is absent. Of course, a small rock-sheet may be sufficient to cause a slow consolidation of such a basic magma. The segregation of ordinary augite out of a rhombic augite points to a slow cooling. It is explained by changes of the physical conditions and consequently of the stability of the minerals during the process of cooling.

The interesting, somewhat undulatory lamellae of the fresh olivine (Phot. 71, Pl. XXIV) were regarded as being caused by tectonical influences after solidification. The olivine crystals with a border of antigorite do not show such stress-lamellae. This fact is explained by the softness of the antigorite which protected the hard grains of the olivine between. In any case the tectonical influence was later than the serpentinisation of the olivine.

Consequently, the serpentinisation which is not caused by tectonical deformation must be very young, the peridotite being already considered the youngest intrusive rock of the district.

In conclusion, a peculiar rock is to be mentioned, only encountered south of Jungbwa, forming dykes in the peridotite.

Macroscopically it presents a white groundmass of feldspar with olive-brown augite phenocrists of 2—3 centimeters each with an olive-green border. Under the microscope the white substance is determined as a slightly sericitic labrador of sharply defined poly-synthetic twin lamellas. Between this plagioclase is found a more or less idiomorphic enstatite with an uralitic border. As in the peridotitic mother-rock, the enstatite is full of ordinary augite which frequently is lamellar, so that usually two uniformly extinguishing augite individuals are recognized within one enstatite.

This gabbro-like dyke might correspond to a younger pegmatitic phase of a granite.

3. The Exotic Blocks of Jungbwa

Shortly before reaching the SW shore of Raksas Lake, the same series of flysch reappears underneath the peridotite sheet which we saw disappearing below it south of Amlang-La, with north-westerly dip. At Raksas the dip of the flysch is 40° to S and SE.

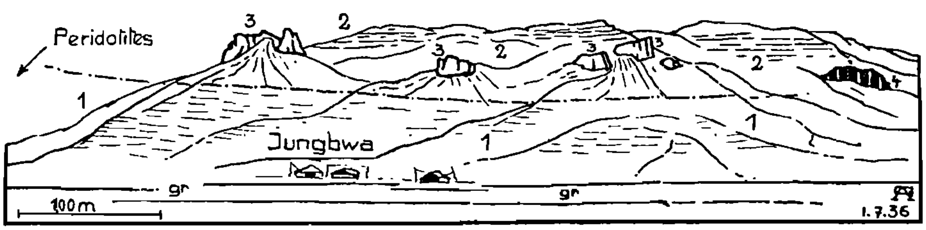


Fig. 147. The Northern Region of the Exotic Blocks at Jungbwa.
1 = black slates (Spiti shales); 2 = complex zone of flysch, radiolarian chert in the upper series; 3 = exotic blocks of Lower Triassic, like those south of Amlang-La; 4 – porphyritic Igneous forming blocks in the flysch; gr = gravel.

It is not necessary to describe the flysch again, because the subdivisions are the same. Moreover, the outcrops are much less continuous than at Amlang-La. The general position is shown in Fig. 147.

The upper series is rich in red radiolarian chert (radiolarite), which is less important at Amlang-La. Under the microscope an exeedingly fine-grained groundmass of quartz appears with some rather coarse streaks. The whole is impregnated with dust-like hematite. The larger quartz grains are devoid of ore and are slightly undulatory. The whole matrix is sprinkled with well-preserved radiolarians (spumellarians?), the same forms as those found in the middle flysch series of Amlang-La.

In the lower part the flysch is mainly a variegated slate with sandstone. It again contains exotic blocks. They stand out of the dull flysch in white and pink, each block with a train of scree below it. Though isolated, they are more or less restricted to the same level. The three largest blocks are estimated at 2000, 4000 and 500.000 cubic meters. The latter is the one on the left of Fig. 147. Although it was not possible to extract determinable ammonites, the whole facies is similar to that of Lower Triassic at Amlang-La. Besides the limestone, there are blocks of igneous rocks in the flysch, of the same porphyritic type as those south of Amlang-La.

The upper boundary to the Spiti shales is not clearly exposed and is only recognized by the different colouring of the debris. Thus, the strike cannot be determined. Howewer, the general dip of the flysch is towards SE, while that of the Spiti is partly towards south. Farther to the north the lower part of the flysch again dips normally towards SW.

4. The Exotic Blocks of the Lower Shib Chu

Intending to seek the northern continuation of the Kiogar thrust sheet, the Shib Chu was followed where the flysch with exotic blocks were found, although interrupted by Pleistocene gravel and conglomerate.

a) The North Side of the Kiogars

Coming from Balchdhura, the northernmost spur of Ghatamemin was crossed, where a good view was obtained over the north side of the Kiogar group. Unfortunately the Flysch with its

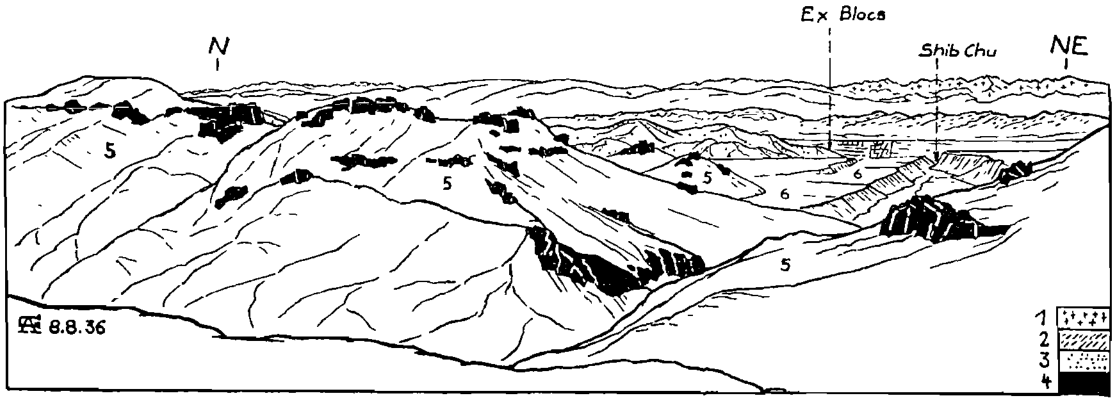


Fig. 148. North End of the Kiogar Flysch with its Exotic Blocks.
1 = Transhimalaya (probably crystalline); 2 = Chilamkurkur zone, north of the Sutlej; 3 = The peridotite region on the west side of Shib Chu; 4 = The exotic blocks of the Kiogar region; 5 = Flysch with igneous rocks; 6 = Pleistocene gravels of the Shib Chu.

exotic blocks dips everywhere below the mighty Pleistocene conglomerate. Only in the far NW the flysch is partly exposed and overlain by the peridotite sheet of the western Shib Chu.

The north-western extension, seen from the northern slope of Ghatamemin, is shown in Fig. 148.

The exotic blocks are usually separated by flysch and igneous rocks apparently older than the flysch. The igneous rocks cannot be separated on account of the decay of the tuffogene parts into flysch-like scree material.

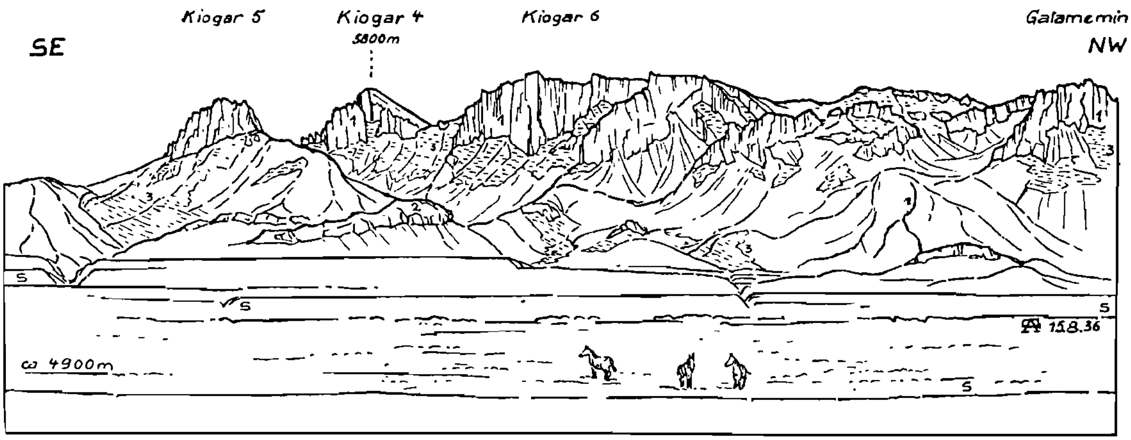


Fig. 149. The North-Eastern Face of the Kiogars seen from the Gravel Plain of the Upper Shib Chu (wild Kiangs = horse-donkies in the fore-ground).
1 = White Kiogar limestone; 2 = Red Triassic limestone, probably Lower Triassic; 3 = Flysch with basic igneous rocks. The latter are not separated; s = Gravel, chiefly Pleistocene.

The upper row of exotic blocks on the north-eastern foot of the Kiogars is merely formed of white Kiogar limestone. The lower blocks north and north-east of the Kiogars Nr. 5 and 6 are red and white, similar to those of Amlang-La. (Fig. 149)

The above sketch shows the whole Kiogar region dipping N or NE and disappearing before the gravel plain. Seen from the north, the Kiogars (4, 5, 6, and Ghatamemin) do not form a continuous mass, but appear like immense blocks intersected with flysch and igneous. The serpentine found in the gap between Kiogars Nr. 4 and 5 (Fig. 127) has the shape of a mighty trunk involved in the flysch, and is possibly younger than it, whereas the more porphyritic igneous rocks are in the shape of blocks in the flysch, and are probably older than the latter. The serpentine of Balchdhura may also be younger than the porphyrite, as indicated by the following petrologic research.

b) The Igneous Rocks of the Kiogar Region

The most striking rock is the serpentine. A specimen from the Balchdhura Pass (foreground of Phot. 45 Pl., XVII) is macroscopically dark green, glittering like glass and of an intensely slickensided surface. On the fracture relics of augite are recognized. Under the microscope the rock proves to be completely serpentinized. Only the mesh-like arrangement of the antigorite reveals its olivine origin without being tectonically much altered. The only persisting relics are large orth-augite which may be regarded as enstatite. Besides fine-grained streaks and patches of magnetite, brown spinell (picotite) also occur. The whole composition of this rock recalls the peridotite south of Jungbwa and of the Shib Chu. The serpentine of Balchdhura too must have been an enstatite-peridotite. It is therefore sup-

posed that in the Kiogar region too the ultrabasic rocks are intrusives younger than the flysch, while the extrusive porphyrite and the adjacent tuff seem to be older than the flysch, but younger than the Kiogar limestones.

Another rock specimen from the Balchdhura is greenish, very fine-grained. Under the microscope an acid lamellar plagioclase is striking. It is an oligoclase-andesine giving the rock an ophitic appearance. Between its laths small colourles augite appears. Because of the small axial angle it is best placed amongst the pigeonite. Chlorite formed of biotite is accumulated between the plagioclase. The chlorite is of ink-blue interference. It is probably a pennine. Titaniferous magnetite with leucoxene border is frequent. Also alkalifeldspar occurs, and here and there a rather large quartz grain. Titanite and secondary calcite, the latter derived from plagioclase, are subordinate accessories. The whole mineral composition recalls somewhat the finest-grained pigeonite-biotite-syeno-diorite of Amlang-La. There, these rocks are certainly younger than the flysch. Perhaps this is the case also at Balchdhura, although the outcrops are not decisive.

Coarser dioritic rocks of Balchdhura, however, are so much altered that almost nothing can be said of the original mineral contents. Only the very fine lamellae of Ilmenite must be mentioned; they probably derive from biotite. This rock resembles the syeno-diorite of Amlang-La with its sparkling biotite in the fine-grained greenish-white groundmass. It is true that the biotite is here completely altered.

Near this diorite is a dark greenish sandstone which at first sight might be taken for a diabase (Fig. 119). Under the microscope it proves to be an arkose-sandstone with igneous material. The single minerals are quartz, plagioclase, chlorite and calcite. Amongst the rock components are some of fine porphyrite with lath-shaped acid plagioclase, just like those of the dark sandstone of Amlang-La. The abundant contents of this porphyritic material recalls again the rocks of the Taveyannaz type in the Alps. Their occurrence as parts of flysch sandstone points also at Balchdhura to a pre-flysch age of the porphyritic tuff and porphyrite (amygdaloid porphyrite) frequently enclosed in the exotic limestones as well as in the flysch. The porphyrite is thus younger than the Kiogar series (Jurassic), but older than the flysch (Upper Cretaceous).

A coarse glauconite sandstone from the lower flysch of Kungribingri was also examined and found to contain, besides quartz and glauconite, large rounded grains of porphyritic rocks with laths of acid plagioclase. Thus the lower Cretaceous (Giumal sandstone) too contains basic igneous material.

Another specimen of a massive green amygdaloid porphyrite from Balchdhura crest above Sangcha Malla is again of different aspect, although the mineral composition of the porphyrite is almost uniform:

The ophitic groundmass is made of andesine laths with intermixed chlorite and calcite, the latter including magnetite as an altered product of the dark minerals which are no longer recognizable.

The block Nr. 2 of GRIESBACH's map, with its abundant Carnic ammonites, is of special interest because of its igneous contact (see p. 150). The small vesicles occur only near the contact and are filled with calcite, while the groundmass is impregnated with hematitic iron as it occurs also in the red limestone.

A specimen from Chirchun Nr. 1 of a green amygdaloid porphyrite again shows the ophitic groundmass of oligoclase-andesine, and abundant leucoxene. The globular vesicles are usually filled with one uniform calcite individual.

The porphyritic rocks of the Kiogars thus are of the same andesitic type as those of Amlang-La. They are extrusive and older than the flysch, while the more basic peridotitic rocks are younger than the flysch, though not younger than the thrusting.

c) The Exotic Blocks of the Shib Chu Gorge

We have seen that the Kiogar series and the underlying flysch with its exotic blocks are bordered towards NE by the Pleistocene gravels. Only north of Balchdhura the flysch continues, but it is covered 8—10 kilometers north of the pass by the young peridotitic igneous rocks. The only place where flysch (dark brown-gray sandy calcareous shale) was again found uncovered is about 20 kilometers south of the Sutlej. North of this place the Shib Chu water disappears at once in a cave and is no more visible. The prolongation of the channel points to a recent change. The flysch too is again replaced by the gravel terraces. These completely horizontal Pleistocene conglomerates are 100—200 meters thick above the river, but may reach far below the river bed. The flysch appears underneath these level terraces, and also the peridotite overlying the flysch in direct contact (Fig. 150).

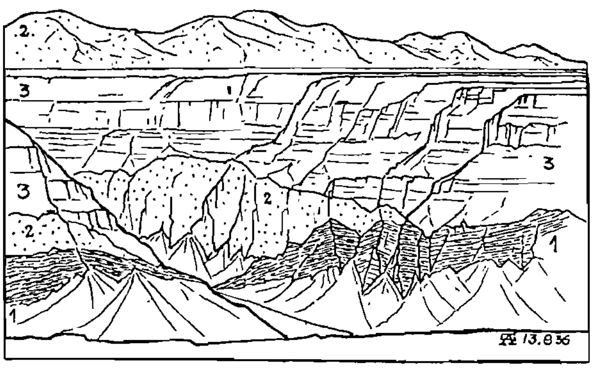


Fig. 150. The West-Side of the Lower Shib Chu Gorge. Peridotite Region in the Background.
1 = Dark, sandy Flysch shales; 2 = Enstatite-peridotite; 3 = Pleistocene gravel-conglomerate.

The peridotite overlies the more or less folded flysch with a distinct unconformity. The igneous contact, however, has also undergone some tectonical disturbance.

Some kilometers farther south, between the flysch and the peridotite, some lénticular, bright limestone blocks suddenly appear against the dark back ground.

The long-sought continuation of the exotic blocks of Malla Johar was thus found. But the mighty series of the Kiogar region is here reduced to a few meters. (Fig 151).

The whole flysch of the Shib Chu dips abnormally 30—40° towards west. The dark brown slates with some completely black layers are sandy and calcareous. Under the microscope a fine-grained groundmass with finely spread graphitoid grains appears, containing sporadic quartz grains. No micro-fossils were found.

The flysch is strongly folded towards the exotic blocks, the disturbance being connected with the blocks. Some smaller blocks are "wrapped up" in crumpled shales. Most of the other blocks and all the big ones rest on the flysch and are covered by the peridotite. Both borders are tectonically disturbed. Between the exotic limestone and the serpentine a zone of 1—2 meters of ophicalcite was observed; it is partly of tectonical origin.

The exotic blocks consist of a gray massive crystalline limestone, with reddish colour here and there. It contains interbedded red slates. No fossils were found, but a correlation with the lower red and white blocks of the Kiogars is probable. Some white blocks also occur, similar to those of Kiogar limestone.

The lower part of the flysch in the Shib Chu is devoid of blocks, and the upper block-bearing flysch is locally absent on account of the unconformous peridotite transgression. This contact, after the consolidation of the peridotite, has become a sliding plane, by which locally ophicalcite was formed at the contact with the blocks, and with the flysch.

The ophicalcite is formed of angular fragments of serpentine, embedded in a calcitic matrix with large calcite crystals. The serpentine is made of greenish scales of antigorite with veins of calcite. Although the ophicalcite contains components of the overlying, less serpentinized peridotite, no more relictic minerals are found in these components.

The peridotite has the same mineral contents as that of Jungbwa. It is an enstatite-peridotite with more or less diallague. The olivine is always bordered by antigorite. No entirely fresh rocks were found. The interesting lamellae of the olvine do not appear distinctly on account of the advanced serpentinisation. The later tectonical disturbance is not deducted from the mineral aspect, but from the well-exposed contacts.

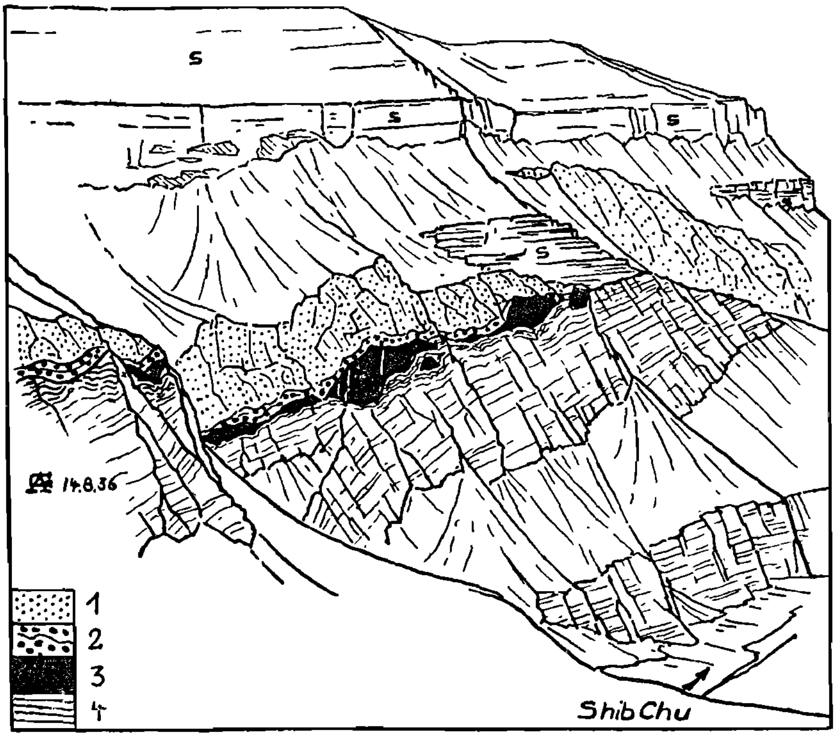


Fig. 151. The Northern-most Exotic Blocks in the Shib Chu Gorge, South of the Sutlej.
1 = Diallague- and enstatite- peridotite; 2 = Tectonic ophicalcite; 3 = Exotic blocks of gray limestone and red shales; 4 = Flysch sandstone and shale; s = Pleistocene-conglomerate.

The exotic blocks are found over a distance of about one kilometer along the Shib Chu. They disappear further south, where the unconformable contact with the peridotite is nicely exposed (Fig. 152).

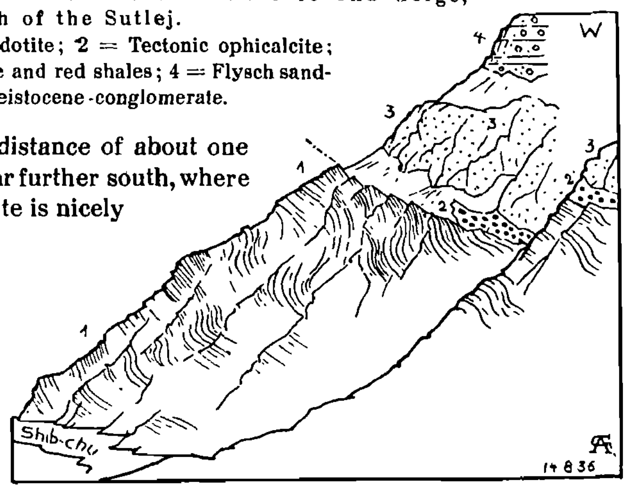


Fig. 152. The Unconformable Contact of Flysch and Peridotite in the Shib Chu Gorge.
1 = dark slaty flysch; 2 = ophicalcite; 3 = enstatite-peridotite; 4 = Pleistocene conglomerate.

The enstatite is the same as at Jungbwa. The diallague is distinctly lamellar, partly uralized and of a greenish-brown pleochroism. The finely distributed magnetite is confined to the antigorite formed of olivine. The brown spinell (picotite) also occurs again. All along the Shib Chu the peridotite is covered by the horizontal Pleistocene conglomerate. Its basis is an irregular surface of former erosion on different levels. Towards the

south, as well as towards the north, the flysch is completely covered, so that all chances to find a connection with the Kiogars were lost. In spite of the conglomerate interruption, the connection of the Shib Chu peridotite with the extended peridotite hills west of the Shib Chu is out of question.

The Kailas Region

1. The Metamorphic Flysch

From the Raksas Lake towards north an alluvial plain with sandstones of about 20 km width is interrupting all exposures. Not only the northern limb of the Raksas anticline is hidden, but also the flysch with its exotic blocks which we expected to find.

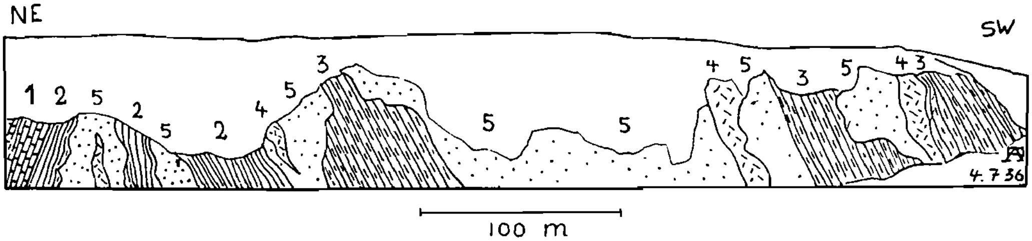


Fig. 153. The Section of Flysch East of Darchén.
1 = limestone layers, about 20 meters thick; 2 = sandy, yellow-brown slates, slightly sericitic; 3 = red sandstone and red slates including red radiolarian chert; 4 = yellow-white to gray more or less dolomitic massive limestone (exotic blocks?); 5 = massive serpentine.

North of the plain, the horizontal conglomerate layers of the Kailas appear at a long distance. West of Darchen they come down to the plain. At Darchén itself and east of it, however, the foothills are formed of a sedimentary series, which strikingly resembles the flysch of Amlang-La. This flysch of Darchén borders towards south on a reddish polygenous conglomerate. More towards south, the conglomerate reaches the gravel plain. Only east of it, and more southerly, flysch constituents of eastern strike are met.

The best outcrops are encountered in the lowest (southern) valley, in which, further up, is situated the Tsumtulphu Gompa, on the east side of the Kailas (Fig. 153).

The southern-most exposures are formed of reddish to red flysch sandstones, passing to red shales with radiolarite-like chert. The latter as well as the occurrence of serpentine-trunks (5) with its enclosed blocks of massive dolomite and dolomitic limestone (4), strongly recall the flysch of Amlang-La and that of the Kiogar region. The dolomite is rarely in direct contact with the flysch; if so, with a sharp boundary.

Somewhat more to the north, the red sandstones and slates pass into gray-brown phyllite, fine calcareous schists and brown sandy slates, which contain further serpentine rocks. Farther towards north, the serpentine intercalations gradually disappear.

Within the slates follows a bed of limestone of 20 meters with a steep local dip towards north, where there are again crumpled slates with a general southern dip. South of Tsumtulphu Gompa, the metamòrphic flysch series is thrust over the nearly horizontal conglomerates and sandstones of the Kailas. (See following chapter.)

The massive, dark green serpentine permits to recognize, even macroscopically, small reflecting planes. They are determined under the microscope as orthaugite, probably enstatite altered to bastite (very low birefringence). The rock was composed mainly of olivine, which has been completely transformed to antigorite. However, the typical network is still preserved. Inside of the olivine-frame, the orthaugite forms large phenocrysts. Some calcite has been segregated. The rock also contains streaks of ore, mainly magnetite.

The yellowish dolomite enclosed in the serpentine is somewhat contact-metamorphous. Under the microscope, besides dolomite, are recognized layers of partly chalcedony-like quartz. The following minerals seem to derive from the basic intrusion, and are enriched on the contact: magnetite, colourless chlorite, and relics of an altered orthaugite.

The serpentine is younger than the flysch, which it crosses. There is no stratigraphic connection of the flysch with the massive dolomitic limestone, which is of a foreign facies. These facts point to the possibility of the lenticular dolomitic bodies being exotic blocks. The analogies to the real flysch, as already mentioned, are in favour of regarding the flysch series on the southern border of the Transhimalaya as part of the root of the problematic exotic thrustsheets. This is only a supposition as long as no bridge of outcrops is found across the 20 kilometer plain. This might be possible by studying the western and eastern prolongations.

The flysch series farther on, outside the serpentine intrusives, is thicker north of Darchen than in the above described more eastern section. The strongly folded calcareous schists and sandy slates are exposed as far as the Gyantak-Gompa, showing a thickness of 4 kilometers (Fig. 154).

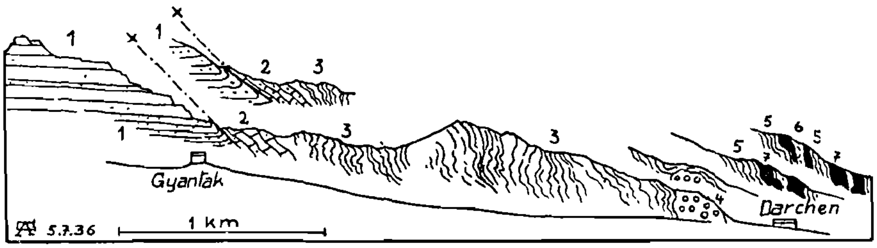


Fig. 154. The Flysch between Darchén and Gyantak Gompa.
1 = conglomerates and sandstones of Kailas; 2 = red conglomerates and slates; 3 = limestones and calcareous schist; 4 = reddish conglomerates; 5 = red sandstone and slate (more in the east); 6 = exotic blocks; 7 = serpentine; x = Himalaya-Transhimalaya counter-thrust.

The flysch sandstone shows under the microscope quartz grains parallel to the schistosity between layers of sericite. Together with the quartz occurs an acid plagioclase rarely showing twin lamellas. Limonitized carbonate is regularly distributed. Also graphitoid substance, some titanite and epidote are present. Chlorite scales are subordinate, and sky-blue to greenish yellow pleochroitic scales of chloritoid are rare. The schistosity is caused by the sericite.

The strata are partly vertical, locally repeated, and appear to be of a great thickness. The northern boundary of the flysch coincides with the counterthrust.

2. The Great Counterthrust (Pl. V)

At the Gyantak Gompa and also some kilometers south of Tsumtulphu Gompa in the eastern Kailas valley, a great thrust contact is exposed, at which the metamorphic flysch series overlies the almost non-metamorphic and nearly horizontal Kailas conglomerate. This thrust-fault is tremendously impressive. Descending from the north, it passes the Tsumtulphu Gompa (monastery). After having walked several kilometers along the undisturbed conglomerates, the first crushing is noticed in the thin sandstone layers a little above the Gompa (Fig. 155).

South of the Gompa, the conglomerate appears at once reversed in the shape of a narrow syncline opening towards north, sharply cut off by the overlying flysch which is

thrust to north. At the basis of the thrust plane, some layers of conglomerate are recognized, which have been detached and shifted over the reversed conglomerate (Phot. 61, Pl. XXII). The thrust plane dips 30—40° towards south.

From E to W, with the increasing thickness of the flysch, the dislocation of the conglomerate layers diminishes. On the left side of the valley, only a sharp turn of the conglomerate underlying the thrust plane is visible (Phot. 65, Pl. XXIII). At some places, there is not only one thrust plane, but the thrusting has resulted in several superposed thrust planes. In the region of Gyantak, the thrust plane hardly reaches the little disturbed horizontal conglomerate (Fig. 154).

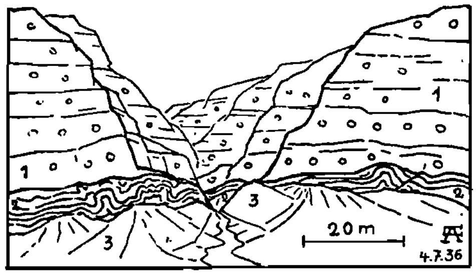


Fig. 155. The crushed sandstones between the thick conglomerate layers above Tsumtulphu Gompa.
1 = conglomerate; 2 = sandstone; 3 = gravel.

The thrust is recognizable just north of Gyantak Gompa and west of it. More to the west, no more good outcrops were found, and in the western Kailas Valley in which is situated the Nyandi Gompa, only the conglomerate series is exposed, the flysch being already covered by the alluvial plain.

The thrust line and the flysch, which is parallel to it, show of a western strike, and thus are at an angle to the Himalayan and Transhimalayan ranges, which strike NW. A similar western strike was found of the exotic flysch south of Amlang-La, above the Spiti-like series. This interesting fact gives an important hint to the problem of the origin of the exotic regions and again points to the flysch zone south of the counter-thrust..

The farther western continuation of the flysch is almost unknown. My advance towards the Sutlej was not far enough to the north to reach the northern flysch zone. Also the Kailas conglomerate seems not to extend that far westward. However, the far western prolongation of the Chilamkurkur series with its southern dip also points to a movement towards north.

3. The Kailas Conglomerate

Already at a distance of a hundred kilometers from the south, the horizontal stratification of the conglomerates display the characteristic feature to the Kailas region including the mysterious summit of 6700 meters. The unrivaled position of this unique mountain of the shape of Shiva's lingam has made it the holiest throne of the gods of the great Asiatic religions (Phot. 59, Pl. XXII).

The conglomeratic series reaches from 4700 to 6700 meters, and thus is 2000 meters thick. The basis may be 1000—1500 meters lower at the western Kailas Valley, while the summit of the Kailas as an erosive remnant may have been at least 1000 meters higher, so that the primary thickness may be estimated at 4000 meters. The main constituents of this enormous body are the conglomerates. Sandstones are less abundant.

a) The Conglomerates

The compact single layers, especially in the northern region, may reach a thickness of over 500 meters, and constitute fantastic erosive forms. Usually, the conglomerate in this northern region only contains thin sandstone intercalations of some centimeters. They increase towards south, where the stratification is nearly horizontal. In the northern part, the southern dip is hardly more than 5°. Only along the northern erosive border, the inclination is up to 10°.

Looking along the western Kailas Valley towards north, a typical crystalline landscape is noticed in the back ground. Already on the western foot of the Kailas, the massive granite appears below the conglomerate, which farther north forms all the lower mountains (Phot.59, Pl. XXII).

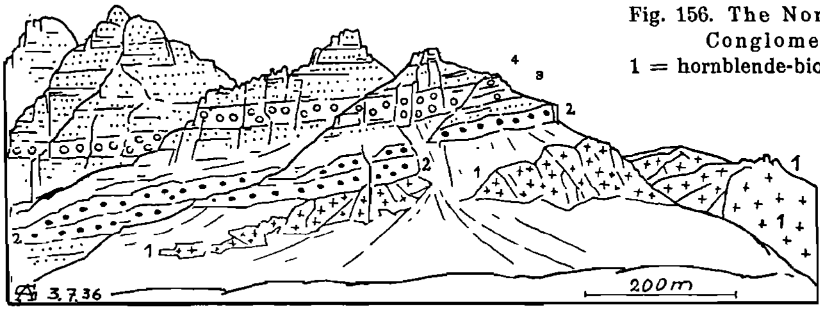


Fig. 156. The Normal Contact of the Kailas Conglomerate on the Granite.
1 = hornblende-biotite-granite; 2 = coarse basal conglomerate with granite boulders up to 5 cubic meters, 3 = fine conglomerate rich in granite pebbles; 4 = coarse conglomerate with boulders of typical extrusive igneous rocks; 5 = normal conglomerate with boulders of typical extrusive igneous rocks.

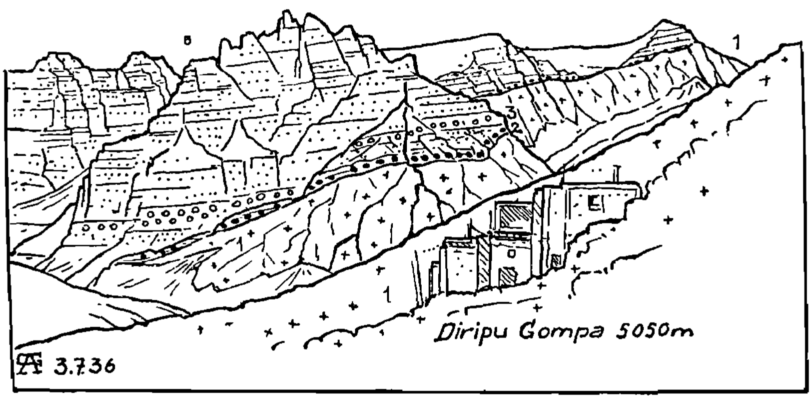


Fig. 157. The superposition of the Kailas Conglomerate upon Granite, seen from Diripu Gompa (numbers like Fig. 156).

At the contact, large rounded blocks of granite up to 5 cubic meters are found on the unequally eroded surface of the granite. They are embedded in a matrix of smaller mainly granitic pebbles. Upwards, the pebbles diminish in size. Farther up, extrusive igneous pebbles of all colours appear. Then follows another coarse conglomerate of more than 100 meters thickness of variegated eruptive rocks and quartzite, including red chert. The pebbles of this zone may be larger than one cubic meter. Those of the overlying conglomerates are of normal size, usually below that of a head. Granite amongst them has become very rare. The pebbles are described in a following chapter.

Only here and there is found white to gray-blue quartzite and hornstone like the radiolarian chert. No carbonate pebbles were noticed, with the exception of one specimen of two centimeters of a yellowish weathered limestone, embedded in a non-calcareous layer. The groundmass of the conglomerates is usually coarse grained, sandy to siliceous. It leads on to the sandstones, which are scarce in the north, but develop towards south, especially in the upper part of the Kailas conglomerate series. Also the size of the pebbles diminishes towards south.

b) The Sandstones

The conglomerates lead on to the sandstones by passages in a vertical and horizontal way. They also are mainly formed of relics of igneous rocks. Especially the upper coarser sand-

stones are true arkoses. The specimens examined under the microscope derive from the lower and southern layers. The size of the grain and the colour (usually greenish grey) are variable. Reddish to whitish sandstones are subordinate.

A coarse greenish arkose-sandstone showed under the microscope subordinate chlorite (probably derived from biotite), and ore. Besides relics of quartzite, the alkali-feldspars are striking: microcline and orthoclase. Frequent too are rounded fragments of extrusive rocks with ophitic lath-shaped plagioclase. Frequently, they are associated to fine ore grains. Here and there are yellow pleochroitic epidote grains. Components of carbonate and metamorphic rocks are wanting, as well as in the conglomerates.

A fine arkose-sandstone has a similar composition, except that the quartz is concentrated in longitudinal grains. Alkalifeldspars are still abundant, and the single myrmekitic feldspars are striking (derivation probably from granophyres).

Other specimens from the south of Tsumtulphu Gompa near the flysch thrust are white coarse arkose sandstones. They are characterized by large quartz grains recalling those of a quartz porphyry, and by zonar plagioclase. The fairly large rounded grains are embedded in a very fine-grained groundmass mainly of quartz and sericite. Alkalifeldspars are subordinate or may be wanting. The alteration of plagioclase produced subordinate xenomorphic calcite. The biotite is relictic and transformed to chlorite with some ore.

The finest grained greenish sandstones carry more chlorite. Besides the plagioclase and the pavement-like quartz are single epidote grains and subordinate zircon. Calcite forms isolated grains, but also here it may derive from plagioclase.

Quite different is the origin of lime in the following sandstones, which belong to the reddish sandstones and conglomerates above the counterthrust:

A specimen from the thrust zone itself (Nr. 4 in Phot. 61, Pl. XXII) may be called a white mylonitic arkose sandstone. It differs even macroscopically by its grain from the other Kailas-sandstones. Under the microscope the quartz grains embedded in a fine mylonitic matrix are angular and broken. The irregularity of the fragments in size and form is the main distinction from the other types of sandstone.

The two specimens of reddish sandstone above the counterthrust are distinguished by their abundance of carbonate. The abundant limonite causes the red colour. The calcite is fine-grained and usually forms the border of the limonite grains.

A coarser type of sandstone is still richer in carbonate, and contains abundant components of red hornstone and red shale. Under the microscope are determined roundish grains of quartz, plagioclase and of eruptive rocks with an abundance of fine ophitic laths of plagioclase and rounded grains of calcite. The composition recalls certain flysch types at Amlang-La. Similar to this composition are the red conglomerates, which are frequent above the counterthrust, and belong to the flysch series. They are distinguished from the Kailas series by their carbonate content.

c) Summary

We observed a general decrease in the amount of the conglomerate and the size of its pebbles towards south. The northern region including the Kailas itself is almost exclusively formed of conglomerate. Towards south, and especially SE, the sandstone layers become more frequent. On the other hand, the large pebbles of Kailas granite diminish upwards in size and frequency until they entirely disappear. In their place follow pebbles of acid to medium-basic extrusive rocks, which were not found in the southern regions. The carbonate pebbles too are very rare or lacking. North of the Transhimalaya however, SVEN HEDIN collected rocks of andesitic flows (HENNIG, 33), which partly correspond to the Kailas pebbles.

All these observations point to a northern origin of the Kailas conglomerate. Towards west, the original gravel fan seems to pinch out, while nothing is known towards east.

4. The Kailas Granite

The normal basis of the conglomerate is a hornblende-biotite granite. It forms bright crests and peaks, very different from the stratified, partly flat-topped conglomerate mountains. The Diripu Gompa and Dolma-La (Pass 5700 meters), north and north-east of the Kailas, are situated amidst a wild landscape devoid of vegetation, characterized by large block fields and sharp, needle-like peaks. The finest view of holy Kailas is that from the north, framed by granite peaks (Phot. 59, Pl. XXII).

In the Tsumtulphu Valley, the corresponding overlap of the conglomerate to that of the western "Kailas Valley" is exposed. The background of it, however, is even beyond the granite, as recognized by the change to softer forms and an indistinct stratification, like that of crystalline schists. Certainly there are no more conglomerates.

The granite is completely massive and contains basic streaks. More northward it may become gneiss-like. Similar macroscopic types have a varied mineral content. The following types were found:

Hornblende-biotite-granite rich in ore. The alkalifeldspar forms large individuals and is mainly microcline, of distinct perthitic crosshatching. It is tarnished by fine limonitic dust, which cannot be optically apprehended, even with the biggest enlargement. The slightly basic oligoclase (An. 28 %) usually is distinctly twin-lamelled. The lath-shaped individuals are zonar, with a somewhat acid rim. The single individuals are partly sericitized. The quartz is less abundant and only of slightly undulatory extinction. The dark minerals are somewhat altered. The hornblende is slightly olive-green and usually associated with biotite. Augite is found in relics inside the hornblende, in a way that suggests an augitic origin of the hornblende. The biotite is intensely chloritized and forms ex-solutions of ore and titanite. The ore is also bound to the dark minerals and usually shows a wreath of titanite. It thus is a titaniferous magnetite. The titanite also may form larger isolated grains.

Macroscopically, the granite is slightly reddish, on account of its reddish alkalifeldspars.

A more yellowish type of hornblende-biotite-granite with abundant basic streaks is of the following composition:

The alkalifeldspar forms grains (macroscopically gray), which are partly microcline, with distinct cross-hatching, partly perthitic orthoclase. Microcline and orthoclase are equally frequent. The plagioclase is similar to the above mentioned feldspars. Also present is a basic oligoclase. Quartz is more subordinate, and dark minerals more frequent and fresher. The biotite shows an intensely olive-brown pleochroism and marginal chloritisation. Chlorite also forms individual blue-green though slightly pleochroitic scales. The small, positive angle of the axes and the lack of anomalous interference-colours point to clinochlor. The hornblende is distinctly pleochroitic and not very homogenous: X = pale yellow; Y = olive green; Z = bluish-green; Z/c = about 18°. Very beautiful are the sieve-like relics of augite enclosed in the hornblende. (Phot. 81—82, Pl. XXVI). Z/c of the augite is 45°. It is colourless. The sieve-like enclosures extinguish unanimously and may be the mother-mineral of the hornblende. Together with the latter, there occurs also a large yellowish titanite. Apatite and magnetite are accessories.

The basic streaks in the granite, of different size, are hornblende-diorite, although of complex mineral contents. The preponderant mineral is a lath-shaped andesine with distinct twin-lamellas. It is partly zonar with a more acid border. The core is more sericitised than the rim. Alkalifeldspars occur subordinately. Some small grains show an

indistinct cross-hatched texture. In large isolated andesine is enclosed small, very clear microcline, which draws attention by its distinct cross-hatching and the low refringence. The general appearance points to new formations within the andesine. The abundant hornblende corresponds to that described above. The typical sieve-like cores of augite are also present. The originally abundant biotite is almost entirely transformed to a distinctly green pleochroitic chlorite. Thereby, fine titanite has been segregated. Inside the chlorite, the biotite only remains in the shape of slightly pleochroitic lamellae. It is striking, however, that just those parts which carry the clearest relics of biotite are characterizend by the presence of long clear stalks of a high refringence and birefringence. This mineral is mono-axial, and seems to be a kind of antophyllite. Every biotite of the slice shows these peculiar enclosures. The titanite is usually abounding in fine grains. Also magnetite is frequent. The less important accessories are apatite and a strongly pleochroitic yellow epidote. Quartz seems not to be present. The fine-grained rock is complotely massive and shows a somewhat ophitic texture on account of the presence of the lath-shaped plagioclase.

A brighter type of granite with less dark minerals reveals under the microscope specially well-formed feldspars. It is a hornblende-biotite bearing granite. The abundant alkalifeldspar is a large microcline with distinct cross-hatching, and a perthitic orthoclase. The formation of microcline lamellae within a homogenous alkalifelspar can be followed. The orthoclase is partly full of segregated albite (albitisation). The large zonar andesine (An. 32—35), shows distinct twin-lamellae, which disappear towards the more acid edge. Frequently, the plagioclase is bordered by a slightly perthitic alkalifeldspar of 2 V = about 70°.

A further type of granite with few dark minerals which are now mainly composed of chloritised biotite, is of interest because of its large phenocrysts of alkalifeldspar with indistinct cross-hatching in a more or less homogenous groundmass. The optical axial angle is so small that it may be anorthoclase. The other minerals are the same as those described. This granite is of such an extension that it seemed to be desirable to submit it to chemical analyses:

Hornblende-and chloritized Biotite-bearing Granite of Kailas-North
(Analyst Prof. J. JACOB)

		NIGGLI values		Type of engadinite-granitic Magma
SiO_2	71,28	si	374	380
AlO_2	14,96			
Fe_2O_3	0,56	al	46	43
FeO	1,02			
MgO	0,49	fm	10,5	13
MnO	0,02			
CaO	1,11	c	6,5	8
Na_2O	4,37			
K_2O	4,32	alk	37	36
TiO_2	0,57			
P_2O_5	0,05	k	0,39	0,5
H_2O+	1,26			
H_2O-	—	mg	0,36	0,25
	100,01			

The type is thus engadinite-granitic.

The granite of the Kailas also may be rather poor in mica, so that the dark minerals are only accessories. Macroscopically, pink coloured orthoclase phenocrysts of 1—2 centimeters are recognized in the white groundmass of quartz and plagioclase. The reddish colour derives from the alkalifeldspars. Under the microscope the large alkalifeldspar proves to be a perthitic to antiperthitic orthoclase. The plagioclase is a normal,

somewhat basic oligoclase of partly zonar development, similar to that of the other granitic varieties.

Whithin these massive granites, aplitic dykes are found subordinately, of not more than one meter in thickness. They draw attention because of their macroscopic density and uniform pink colour, although only deriving from the alkalifeldspar.

Compared with the granite, the aplites are rich in quartz and almost devoid of dark minerals. The only dark mineral recognized macroscopically is a black tourmaline, which appears in thin needles of 2—3 centimeters' length. Under the microscope, the feldspars reveal themselves mainly as oligoclase in the shape of elongated twinned individuals. Microcline and orthoclase are subordinate. Quartz is abundant as compared with the granite, and forms roundish inclusions in the feldspars. The dark minerals are missing. In their place a blue-gray pleochroitic tourmaline is observed.

Age of the Kailas Granite, and Comparison with the Himalayan Granites

No precise age-determination can be given. In any case, the granite is older than the conglomerate which contains the basal granite in boulders. The upper chronological limit thus depends on the age of the conglomerate. The latter contains abundant pebbles from the regions north of the Transhimalaya. The eruptive rocks therefrom are andesite, basalt, dacite and liparite (HENNIG, 32, p. 187).

Thus, the Kailas granite seems to be not younger than Eocene. The lower limit is unknown as long as no contacts with older rocks are found. They have to be looked for in the north. If no tectonical disturbance has occurred for a long period, the massive structure does not necessarily suggest a Tertiary age.

Compared with the younger Himalayan Granites (Api glacier and Bhagat Kharak), the Kailas granite is less fresh. But there is no difference in weathering between its former surface and the lower part. Like a guide fossil, the younger Himalayan granites carry tourmaline in abundance, while this mineral seems to be lacking in the Kailas granite, and only was found in an aplitic dyke. The tourmaline granites of the Himalaya are highly micaceous. The Kailas granite on the other hand bears hornblende derived from augite, which is an indication of a secondary mineralogical generation. The biotite, furthermore is almost entirely chloritized.

Possibly, the granite passes on to a gneiss towards north. The tourmaline granite of the Himalaya, on the other hand, breaks across the stratified or schisty rocks. All these considerations poiut to a higher age of the Kailas granite. The corresponding granite of the Himalaya may have been already metamorphosed, while the Kailas granite remained undisturbed.

An interesting comparison is afforded by HAYDEN's description of the Kyi-Chu-Granite (23) of the Lhasa region. It is also a hornblende-granite with biotite. HAYDEN insists on the difference with the Himalaya granite. The Kyi-Chu granite is regarded as Upper Cretaceous, although no proofs are given.

We thank the following petrological and mineralogical research to Professor Dr. C. BURRI.

Petrology of the Volcanic Components of Kailas Conglomerate

by C. BURRI

The igneous components composing the bulk of Kailas conglomerate have been sampled systematically by A. GANSSER during his trip in the Kailas region. Therefore his collection, although comprising only 25 specimens, may be taken as fairly representative. For micro-

scopic examination 19 specimens have been sectioned. Acid rocks predominate by far amongst the pebbles.

For the purpose of petrographic description the rocks may be arranged as follows:

A. Volcanic rocks
  1. Liparites
  2. Granophyres
  3. Dacites
  4. Andesites

B. Volcanic tuffs
  5. Liparitic and dacitic tuffs

C. Holocrystalline rocks of aplitic character

This arrangement is based on the mineralogical composition as shown under the microscope. As most of the rocks are hemicrystalline and contain much glass, it is quite possible that chemical analyses would show certain of the rocks described here as liparites, dacites or even andesites to belong to the same magmatypes.

The plagioclases have all been determined on the universal stage, making use of the diagrams published by M. Reinhard for the interpretation of the measurements.

A. Volcanic rocks

1. Liparites

Nr. 240. Biotite-Liparite. The rock is grey-black with numerous small phenocrysts. The microscope shows the rock to be hemicrystalline-porphyric with phenocrysts of quartz, orthoclase, plagioclase and biotite. The quartz is mostly rounded and corroded with inlets of the groundmass. The orthoclase is turbid from beginning of alteration and shows signs of secondary albitization. Some Carlsbad-twins have been recognized. The plagioclase with lamellar twinning is basic oligoclase about An_{28}. Biotite is scarce, there are only a few individuals which are almost entirely transformed to chlorite and opaque ore. There are also nests of optically negative secondary epidote. The groundmass shows different types of structure. Cryptocrystalline bands alternate with patches of finely microcrystalline character. There is pronounced flow-banding.

Nr. 230 is annother specimen of biotite-liparite of similar aspect. There is a somewhat great amount of phenocrysts. They are of the same general character but some of them show protoclastic influence. The plagioclase is more basic, being andesine An_{30}. In addition to the chlorite and opaque ore there is one single grain of brown pleochroic hornblende, marginally transformed into ilmenite and titanite. Some individual ilmenite grains might be of similar origin. There are also some stout apatite prisms. Another specimen (Nr. 234) is dense, violet and shows no phenocrysts in the section. It is entirely made up of a partly cryptocrystalline, partly microcrystalline quartz-rich groundmass with flakes of secondary muscowite and chlorite and grains of opaque ore. Being an acid rock without femic minerals, it has been classified with the liparites.

2. Granophyres

The two identical specimens Nr. 222 and 232 are almost entirely made up of quartz and alkaline feldspar in granophyric (micropegmatitic) intergrowth. The slightly perthitic alkaline feldspar forms rectangular nuclei framed by the granophyric fabric, the elements of which vary somewhat in size, being in some places finer, in others corser. In addition there are some individual grains of quartz, some well-developed albite of composition An_{10}, as well as chlorite, apatite, zircon and opaque ore.

3. *Dacites*

Nr. 227 is a typical biotite-dacite. The structure is hemicrystalline-porphyric with phenocrysts of plagioclase, biotite, pyroxene and quartz. The plagioclase is idiomorphic, of tabular habit and somewhat turbid from incipient alteration. The lamellar twinning is still well perceptible. The composition is andesine An_{35-40}. The biotite is lath-shaped and only slightly pleochroitic due to some bleaching. There is also some alteration to muscovite. The pyroxene is monoclinic and slightly altered. Quartz forms some coarse grained mosaics in the cryptocrystalline groundmass.

Other types of dacites are representend by the Nrs. 223, 225, 226 and 238 which are all very similar. They all contain phenocrysts of plagioclase, decomposed femic constituents, and in some cases quartz in a holocrystalline groundmass. The plagioclases are idiomorphic with tabular habit, and twinning is well developed. The composition is andesine varying from An_{30-40} in the different specimens. There is no perceptible zonal structure. The femic constituents have wholly disappeared by alteration to chlorite, epidote and opaque ore. The former presence of biotitie and hornblende phenocrysts is indicated by the shapes of swarms of opaque ores and nests of epidote. Quartz, if present as phenocryst, shows rounded forms. The groundmass is holocrystalline and made up of well idiomorphic lath-shaped oligoclase with xenomorphic ortholase and quartz. The femic minerals of the groundmass have been wholly transformed to opaque ores, chlorite and epidote.

4. *Andesites*

The three specimens of andesite available for study (Nrs. 235, 237, 241) are all badly altered. They are of hemicrystalline-porphyritic structure with phenocrysts of plagioclase. The femic constituents which must have been formerly present have all disappeared as a consequence of alteration. The groundmass seems to have been hyalopilitic in some cases and is also much decomposed. The plagioclase is idiomorphic, tabular and twinned. The composition is andesine varying from An_{40-35}. There is much secondary epidote. The femic phenocrysts which seem to have formed glomerophyric aggregations with the plagioclases are all entirely transformed into chlorite and calcite. The chloritic patches contain skeletons of opaque ores with leucoxene. In Nr. 241 there are also very interesting octahedrons of titanomagnetite in which the lamellas of ilmenite have been replaced by titanite or infiltrated epidote. Epidote is present everywhere in the slide and forms nests together with quartz. The groundmass of the andesitic rocks is also very much decomposed. Laths of twinned oligoclase with almost straight extinction, and chlorite as well as epidote and opaque ores are the chief components. There is a slight fluidal arrangement of the feldspar laths.

B. Volcanic tuffs

5. *Liparitic and dacitic tuffs*

Nr. 231 is a typical example of a liparitic tuff. A very inhomogeneous, partly devitrified groundmass contains more or less irregularly shaped fragments of corroded quartz, perthitic orthoclase, andesine An_{35}, apatite, as well as lapilli which are identical with the groundmass of the different liparitic, dacitic and andesitic rocks which have been described in full detail. They contain also phenocrysts of plagioclase and opaque ores probably resulting from the resorption of femic minerals. Parts of the groundmass are a very fine example of arc-structure ("Bogenstruktur") as formed by shreds of partly devitrified glass with concave outlines, originating from the breaking down of highly vesicular glassy lava.

Nr. 223 is similar to the preceeding one, except that in addition to the components mentioned above, there are also fragments of pumice. Vesicles are filled with quartz and chlorite. Chlorite is also present in the groundmass; arc-structure is well developed.

Nr. 236 is similar to the two tuffs already described. As it does not show any orthoclase it may be rather called a dacitic tuff. There is much secondary chlorite and calcite.

C. Holocrystalline rocks of aplitic character

1. Porphyric aplitic granite

Nr. 224 shows phenocrysts of perthitic orthoclase and finely twinned oligoclase An_{20-25}, as well as of xenomorphic quartz, embedded in a groundmass consisting of a panxenomorphic aggregate of quartz, orthoclase and some oligoclase. There are also a few flakes of biotite altered to chlorite and some opaque ore.

2. Porphyric quartz-dioriteaplite

This rock (Nr. 229) shows phenocrysts of idiomorphic basic oligoclase (An_{25-30},) finely twinned, and of some biotite, slightly bleached. The groundmass is made up of quartz, oligoclase and some microcline-microperthite, the two latter beeing intergrown with the quartz.

3. Inclusions of alkaligranite-aplite in (?) andesite

Specimen Nr. 239 is very important as it shows how aplitic rocks of the types represented by Nrs. 224 and 229 just described, occur as accidental xenoliths in volcanic rocks as described in the foregoing paragraphs.

The inclusion is an aplitic rock made up of quartz, perthitic alkaline feldspar, partly albitized, together with some biotite. At the margin against the including lava, the inclusion is somewhat crushed and the constituents are broken.

The lava (or tuff?) shows phenocrysts of basic oligoclase An_{28} with much epidote and pseudomorphs after ? augite, also with much epidote and chlorite in a dense cryptocrystalline groundmass. A more coarse-crystalline patch in the groundmass shows lath-shaped oligoclase and could also be taken as a lapillo. In this case the rock should be classified as a volcanic, andesitic tuff. The strongly decomposed state does not permit to decide between the two possibilities. The rock is transversed by veins of quartz and epidote.

D. Origin of igneous components of Kailas Conglomerate

The source of the material which builds up the Kailas Conglomerate seems to be situated in the North of the Transhimalaya as pointed out by GANSSER. Great masses of probably Eocene liparites, dacites, andesites and basalts, with corresponding tuffs, have been recorded from there. It is therefore of great interest to compare the Kailas rocks with those of the Transhimalaya collected by SVEN HEDIN and examined petrographically by A. HENNIG[1].

As a whole and as far as correlations of volcanic rock series are permissible from thin section studies alone without chemical analyses, the resemblance of the rock types seems to be quite satisfactory and it is rather reasonable to regard the provenance of the Kailas pebbles studied here as situated in these regions, especially in the Bongthol Transhimalaya.

[1] SVEN HEDIN, Southern Tibet, discoveries in former times compared with my own researches in 1906—1908. Vol. V. Petrographie und Geologie von Prof. ANDRES HENNIG. Stockholm 1916.

REVIEW AND CONCLUSIONS

After the local descriptions of what we have found on our traverses regarding structure, stratigraphy, petrology, morphology and glaciation, we shall now try to review our observations in a more general way, the geological map at hand.

Stratigraphy

The Lower Himalaya

The sedimentary formations of the Lower Himalaya are situated south of the Main Central Thrust, and below the thrusted exterior outliers of crystalline rocks. They have been deposited in a zone between the main crystalline root and the autochthonous region.

In other words, the geosynclinal zone now forming the Lower Himalaya was situated on the northern border of Gondwanaland.

The striking fact of an almost *uniform sterility* of these formations is yet unexplained. Our search of microscopic fossils in the limestone was in vain, in spite of the fact that in places it has conserved the original structure as far as 90—100 kilometers behind the main boundary thrust (Pipalkoti-Gona). If shells had ever been present, they would at least have left some traces.

The fundamental question of the *original superposition* is mainly attached to the grade of metamorphism. In the front region of Simla and SE of it, called Krol Belt[1], the geologists of the Survey of India like Pilgrim, West and Auden, have lately made great progress in establishing differeut thrust sheets, which permitted also to determine the normal sequence. It is from above:

Tal (quartzite of great thickness)		Blaini (boulder bed, tillite)	
Upper Krol limestone	Krol[2]	Nagthat and Chandpur	Jaunsar
Krol red shales		Bansa limestone	
Lower Krol limestone		Mandhali	
Krol sandstone			
Infra-Krol (shales)			

The Simla slates, which are regarded as still older, belong to another, autochthonous to parautochthonous region, and thus cannot be directly coordinated.

Of the above series, the Blaini boulder bed is regarded as a tillite of Carboniferous age. This results from a comparison with the Talchir tillite in the Salt Range, which, by its stratigraphical position is determined as Upper Carboniferous (**8**, p. 205). If the coordination with the Himalaya is correct, this tillite has the value of a guide horizon. Under the kind guidance of Mr. J. B. Auden, we have seen the Blaini in Tehri State NW of the Ganges, where we could collect some striated pebbles of glacial origin. The apparently normal succession there according to Auden begins with the thrust upon the Eocene Subathu quartzite.

[1] J. B. Auden, The Geology of the Krol Belt. Red. Geol. Survey of India, vol. LXVII, 1934.

[2] After the Krol mountain 7393′ on the road to Simla.

1. Chandpur (purple and green siliceous slates),
2. Nagthat (purple and green quartzite),.
3. Blaini (tillite and dolomite),
4. Infrakrol (black pyritic slates) passing to
5. Krol, limestone and dolomite of great thickness,
6. Tal, huge series of quartzite with slates at the basis.

On top of the latter, Mr. AUDEN has found a calcareous sandstone with poorly preserved shells[1]. Their determination if possible will throw a light into the darkness of our chronological knowledge.

If the Blaini is Upper Carboniferous, the Krol would naturally have to be regarded as Permian. The Krol of Tehri, as well as the supposed Krol of Kumaon (Kanari China) resembles strikingly indeed the mighty limestone series of northern Siam. There, in 1935, the writer has seeked for a long time in vain for fossils in the limestone, which partly also has preserved its original dense structure or darkness, until finally and very locally, some beautifully conserved *Fusulinidae* of Middle Permian age were found.[2] This limestone in Siam borders with a surface of erosion to an overlying series of minutely stratified siliceous shale, banded in black, green and white, in which Triassic *Daonella* were found. Near the basis, large blocks of the Permian limestone are embedded. Similar to this, at Masrana on the road east of Mussoorie we came, under the guidance of Mr. AUDEN, to an exposure, where the Krol limestone, with a basal conglomerate is overlain by about 100 meters of minutely stratified siliceous shale and chert, banded in black, green and white, containing some phosphatic nodules. This series, which also may be Triassic, passes via micaceous slate to the Tal quartzite, which tentatively is regarded by AUDEN as Jurassic or Cretaceous.

In Kumaon, we have only traversed the corresponding border region at Naini Tal, where we think to have established a mainly normal series from the China-Peak to the Lariakanta (Fig. 20). Tentatively we have correlated the great series of limestone of Naini Tal (1000 meters or more) with the Krol (following MEDLICOTT), the mighty series of grey and purple slates below China-Peak (400 meters or more), with Lower Krol, and the underlying variegated quartzite (500 met.) with shales or slates with Nagthat-Mandali. In Naini Tal nothing above Krol was found, and the Blaini Tillite below it was seeked in vain.

If now we compare the border region from Simla to Naini Tal with that 800 km further east in eastern Nepal and the region of Darjeeling, we find a striking difference stratigraphically as well as tectonically: There, above the Siwaliks, the Himalayan border formations are reversed. The carboniferous not only is represented by a reversed basal conglomerate (after Fox), but also by an anthracitic series with prints of *Glossopteris* leaves. Already MALLET, in 1874, considered this Damuda-series as equivalent to the coal bearing Gondwana formation. In its place the Krol is missing. But about 60 kilometers further east, a mighty limestone and dolomite series reappears. It is the Baxa of MALLET, situated above the Damudas, and below the Dalings. At once the question arises, whether the Baxa are equivalent to the Krol. If so, the reversed basal conglomerate of the Darjeeling section could not be correlated with the Blaini, but would be a younger conglomerate above the Krol.

The correlations of the border region of Naini Tal, with the region NW of the Ganges having already been difficult, we come to the still more difficult stratigraphical problem concerning the sedimentary series of the interior Lower Himalaya.

The small outcrop of Bhowali excepted, the next important sedimentary series was met north of Ramgarh (Pl. III, Sect. 6a). The limestone and dolomite of several hundred meters in

[1] The facies resembles the Niesen sandstone of the Alps.

[2] A paper on northern Siam, which will give detailed informations, is in preparation in collaboration with Dr. H. HIRSCHI.

the shape of marble are interbedded in quartzite. But north of the "North Almora Thrust", we come again to partly non-metamorphic thick limestones which strikingly recall the Krol NW of the Ganges. But whether the quartzites overlying this "Krol" belong to the Tal or not, is an even more delicate question. Actually we have found almost everywhere a mighty sequence of quartzite overlying the limestone series in the Lower Himalaya of Kumaon.

If we step further to the interior, we come to the largest limestone zone of the lower Himalaya. It forms from SE to NW the zone of Balwakot-Tejam-Kapkot, 10—20 km wide, ending at Wan, but reappearing below the quartzite in the shape of (stratigraphic) windows on the Nandakini and Alaknanda Rivers. This series is partly argillaceous, the limestone and dolomites being interbedded with dark slates. The carbonates are usually crystallized, but in places (Gona Lake) almost non-metamorphic. North of Tejam the succession dips so regularly northward that the thickness can be estimated over 5 kilometers! In Section 6 c, Pl. III, the visible part of the carbonatic series is over 3 kilometers. Of course, the question arises again, whether there are secondary thrusts concealed, for which no positive data were found. At Pipalkoti, where the series is folded, and cannot be repeated, the thickness is about 1500 meters although the greater part may remain below the surface. Below Balwakot on the Kali, the vertical or nearly vertical series is about 5 kilometers wide (Pl. II, Sect. 4a).

Some particularities shall yet be mentioned which may give hints to future correlations:

At the iron bridge of Kapkot over the Sarju, and in Ramganga Valley, 3 km NW of Tejam, a peculiar intercalation of conglomerate was found, containing large quartzite pebbles (pp. 40 and p. 41).

At Badolisera (p. 31) and on the Kali (p. 36) B a r y t e s connected with the limestone were found in large deposits.

At Berinag (p. 33), on the Gona Lake (p. 50), and in other places, the facies of the carbonates is characterized by uncountable primary repetitions of limestone and siliceous dolomitic layers (analysis p. 49). Whether or not the limestones indicated on the geological map belong to the Krol series (and the overlying quartzites to the Tal), we cannot judge. We only are positively of the opinion that they are much younger than the crystalline series thrust upon them.

Not only the c a r b o n a t i c sediments, but also the quartzites are of an amazing thickness. At Bageshwar, for instance, they are so regularly folded that they cannot be repeated. The thickness is more than two kilometers, perhaps up to 3 km (Pl. III, Sect. 6b). The quartzite series between the quartzporphyry and the limestone of the Ramgad is about 2 km thick (Pl. III, Sect. 6a). It may be recalled that the Tal series NW of the Ganges has a normal thickness of about 2 kilometers.

Besides the carbonatic series with slates and the quartzite, another rock is an important member of these sedimentary regions, although of igneous origin. Indeed, the chloritic a m p h i b o l i t e sills form in some places like the Alaknanda at Karnaprayag an important member of the stratified complex. Some greenish schists, like those of Ata Gad might perhaps have been originally tuffaceous clays, or marls, although all the slices made of green rocks have been microscopically determined as of basic igneous origin. In no place did we find the green basic rocks cutting across the adjacent sediments. They are thus regarded as underflows or sills, contemporaneous, or rather somewhat younger than the sedimentaries between which they occur. Considering the mighty deposition of carbonate and sandstones of the Interior Lower Himalaya, the dioritic intrusion appears to be connected with the geosynclinal down-warp of those remote periods, and the absence of acid intrusions to be in connection with the proximity of the "Tachylitic layer" of the earth's crust underneath.

The youngest of the basic sills may be that of Naini Tal, in the Krol series. Whether or not these basic igneous rocks are in connection with the famous Carboniferous and younger traps of Kashmir, is still an open question.

The Tethys Himalaya

Introduction

When the isopic lines of geosynclinal sedimentation are not at a right angle to the lines of folding and thrusting, but more or less parallel to them, as is the case in the Alps, any major thrust must show a difference in facies from the underlying and overlying series.

Our tectonic interpretation of the Main Central Thrust is indeed strikingly confirmed by the differences in facies. Corresponding to the greatest Himalayan thrust mass from Sikkim to the Sutlej over more than 1000 km, there is also the greatest contrast in the Himalayan facies development: Below the thrust are the unfossiliferous formations of undetermined age. Above the thrust, forming its normal superposition, is the facies of the Tethys Himalaya, a chiefly marine geosynclinal sequence from the pre-Cambrian up to the Cretaceous, which partly abounds in well-preserved fossils. No wonder that the first observer of the Central Himalaya, STRACHEY in 1848, was fascinated of these regions, where he found marine fossils of Silurian age. A great progress in science was made at the end of the last century by the Austro-Germans of the Geological Survey of India: DIENER, GRIESBACH and v. KRAFFT and by the additional work of HAYDEN. It is surprising though, that during this century no more attention has been paid to these most beautiful regions,—perhaps because the maps and sections of GRIESBACH were considered as conclusive. Within this interval of nearly fourty years, the tectonical views in the Alps have made striking progress and furnished a new basis also for the stratigraphical research in the Himalaya.

The Crystalline Basis (Vaikrita, Archean)

The tectonical and petrographical research have both resulted in the recognition of an originally sedimentary basis of the great crystalline central series, as already known. The magmatic injections, intrusions and dykes indeed are all younger than the original sedimentary deposition. The garnet schists owe their origin to clay, the psammite-gneisses, which are of wide distribution, have been argillaceous sandstones and the lime silicates and biotitic marbles were limestones and dolomites. AUDEN has photographed even the original diagonal bedding of the psammite gneiss (4, 1935).

The crystalline series has a thickness of 10 (Kali) to 20 kilometers (Nandakna), and 15 km where it is most regular (Gori Ganga). The original sediments have partly been fused and replaced by magmatic processes at the depth (intrusion and migmatisation). The enormous thickness of the original deposits already results from the psammitic series of the Alaknanda at Pandukeshwar, where the regularly bedded quartzites of over 9 kilometers thickness are at once recognized as former sandstones.

These former sediments must be older than the overlying Martoli series and generally are regarded as Archean. During an interval of about a milliard years they have been covered by younger sediments in periods of subsidence, until they reached the depth of about 30 kilometers, where they not only became regionally metamorphosed by heat and pressure, but also granitized (migmatized) or completely fused. At the end of this long period followed the paroxism which by thrusting brought these oldest metamorphic sediments up to the surface again within a relatively short time.

The Martoli Series (Algonkian)

In 1891, C. GRIESBACH has introduced the pretty name of Haimanta[1] System, applied to "all the thickness of strata lying between the crystallines (gneiss and Vaikritas), and the lower

[1] Haimanta means in sanscrit "snow-covered".

Silurians" (20, p. 20). Unfortunately, this name could not be maintained, although it was generally accepted until now. Indeed, in the maps and sections GRIESBACH has drawn an almost straight line or fault, which does not exist, as the lower boundary, passing arbitrarily through the middle part of the great phyllitic quartzite series, for which we propose the name of Martoli Series. This important village Martoli on the Gori Ganga below Milam lies in the central part of this huge sedimentary series, which, in GRIESBACH's map, is included in the "Metamorphic and Granite".

Accordingly, also the highest summit of the Central Himalaya, Nanda Devi, 7820 meters, as well as Nanda Kot, were always regarded as made of granite and gneiss, although they belong already to the sedimentary Martoli series (Pl. III, Sect. 6c).

The Martoli series is chiefly formed of little metamorphic calcareous and non-calcareous phyllites, with quartzite layers, and is joined to the underlying crystalline series not only by a passage in decreasing metamorphism upwards, but also by some of the last pegmatite dykes (Rilkot, Pindari glacier, eastern summit of Nanda Devi).

After discounting the repetitions by folding and contortion, the thickness is roughly estimated to attain 5 kilometers[1]. Towards east, the Martoli series almost disappears, and is represented at the Kali only by the Budhi schists with their characteristic biotite porphyroblasts. Whether this reduction is due to igneous activity or to stratigraphic changes, we cannot judge.

The age, as compared with HAYDEN's description of the Spiti region, must be pre-Cambrian, and is regarded as Algonkian. The distribution is shown on our map and sections.

The facies of the Martoli series is that of flysch, an unfossiliferous geosynclinal accumulation of clay, marl and sand on a sinking ground.

The Ralam Series (Basal Cambrian?)

Under this name the important series of basal conglomerate with quartzite and dolomite was described, which is exposed on both sides of the dangerous Ralam Pass (5500 meters, between the Lissar- and the Gori Valley).

Entirely new conditions of sedimentation are introduced. The conglomerate, mainly formed of quartzite pebbles, up to the size of a head, in a black or red quartzitic ground mass, similar to greywacke, is of varied thickness, and may reach 100 meters (Ralam-N). In the two places where we found the basis exposed (Ralam-N and Gori Ganga above Milam, Fig. 104 and 107), it seemed to rest unconformably upon the Martoli phyllites. The primary unconformity, furthermore, was tectonically deformed and partly became a sliding plane. The best place to study the lithology of the conglomerate is Samgong on the Gori above Milam, where huge blocks have fallen down from the walls (Phot 38, Pl. XVI).

The conglomerate passes gradually into a gray to purple and green, very hard and massive quartzite. The thickness in the Lissar Valley and on the Nipchungkang glacier is estimated at 500—800 meters.

The top of the Ralam Series on the Ralam Pass, as well as on the upper Gori, is made of yellow to orange weathered massive dolomite of 50—100 meters.

The Ralam Series is completely wanting in the Kali section. It was followed up from the mouth of the Dhauli into the Lissar until the upper Gori, which is 55 kilometers.

Forming the conformable basis of the Garbyang series, which is considered as Cambrian, we tentatively regard the Ralam series as the basal Cambrian. The conglomerate shows that there was a great interruption of normal marine sedimentation at the end of Algonkian time.

[1] Captain STRACHEY (59, 1851), considered the thickness of his "azoic slates" as 9000 feet. GRIESBACH (20, 1891, p. 50), considered this figure to be "very greatly over-estimated" and gives it 4000 at the most.

The Garbyang Series (Cambrian)

This name is taken from the important village of the Kali Valley, where this series or system is excellently exposed. It forms the upper part of GRIESBACH's Haimanta system. The facies, as a whole, seems to be constant as far as we could observe, from Tinkar or the Nampa valley in Nepal to the Gori valley above Milam, which represents a distance of 100 kilometers in a WNW direction.

The characteristic rock is a more or less slaty and slightly sericitic (phyllitic), very fine-grained calcareous sandstone, or a sandy to argillaceous, partly dolomitic limestone of brownish weathering, with green chloritic banding especially in the lower part. The chloritic part seems to be the altered product of a basic tuff blown into the sea.

The thickness, in the Kali section, is 4,5 kilometers. The dip, with the exception of the basal part, is so regular that this thickness seems to correspond about to the original thickness. A similar figure was found at the Dhauli section, while in the uppermost Gori valley above Milam the sequence is reduced to about 1,5 kilometers. It is not known how much of this decrease is due to tectonical influence.

According to the Trilobites found by HAYDEN (1904) in the uppermost part of the Haimantas in Spiti, the age is considered as Cambrian. Certainly, the Garbyang series is not pre-Cambrian, as demonstrated by several large, though badly preserved flat Gastropods, which we found in the typical, slightly sericitic calcareous Garbyang phyllite on the Shiala glacier. This is also confirmed by the Crinoid limestone of the middle Garbyang on the Dhauli. Finally, the first calcareous sandstone above the Garbyang slates has furnished an Ordovician Fauna. We thus can hardly fail in regarding the Garbyang series as Cambrian.

The facies again is similar to flysch, though distinguished from the Martoli series by a high content of lime, which for the whole sequence, amounts to 20—40 percent.

The Shiala Series (Ordovician)

We crossed several times the zone between the Garbyang series and the red Silurian crinoid shales (Kali, Shiala pass, Dhauli Ganga, Gori Ganga), but only on the Shiala pass accessible outcrops of this series were found, though even there the greater part is covered by glaciers, whilst the rest is partly inacccessible. The best and almost continuous outcrops were seen on the right side of the Dhauli Gorge, where a study in situ, if at all possible, would need exceedingly difficult climbing.

Summarizing our description of the Shiala pass, we may state that above the typical Garbyang division follows a series of about 400—500 meters of variegated shales with intercalations of sandy limestones or crinoid breccia of brown weathering. The Ordovician trilobite and the brachiopods mentioned on page 121 were gathered in situ from the calcareous sandstone of about 60 meters thickness on top of the division which we have proposed to call the Shiala series. A similar bed in the lower part also proved to contain brachiopods, but on account of avalanches, the place was too dangerous for collecting.

Probably STRACHEY's discovery in 1848, of "Lower Silurian" fossils corresponds to what would now be called Ordovician. Unfortunately STRACHEY did not mention the localities.

On the trail along the uppermost Gori valley near Dung, loose moraine blocks of similarly fossiliferous calcareous sandstone were met, though the series is only partly exposed.

The brachiopods and the trilobite collected from the top-layer of the Shiala series at the mouth of the glaciated Tsherpedang valley, leave, according to Professor JEANNET's determination, no doubt about the Ordovician. The question, whether the overlying variegated series, or how much of it, should still be regarded as Ordovician, remains unsettled.

The Variegated Silurian

This subdivision was called "Red Crinoid Limestone" by GRIESBACH, and regarded as Carboniferous in one place, and as basal Silurian (Quartz shales of Kali) in another. The first of these mistakes was removed by HAYDEN (22, 1904, p. 29), who "ascertained that the Spiti representative of the 'red crinoid limestone' is certainly not younger than upper Silurian". This was the result of correlation of the Spiti sequence with that one of Kumaon. The coral limestone, which in Spiti underlies the red crinoid limestone, figured by GRIESBACH also in the Kali section, has not been encountered by the writers in Kumaon, although there seems to be no break of deposition above the Shiala series.

No other formation of the Tethys- Himalaya presented us so many stratigraphical difficulties. Not only is there a primary repetition of limestones and marly to siliceous shales of varied colour from top to bottom, but the streaky shales are usually intensely folded or crumpled. In addition, no characteristic fossils were found. The small white fragments of crinoids are only a lithological characteristic. We can thus only give a general idea of this formation.

A subdivision was clearly observed on the Shiala pass only:

a) 200—300 meters of red to green and grey shales with layers of white limestone, characterized by smaller blood-red shale layers, and a rusty weathered dolomite in the upper part;
b) 500—600 meters of shaly lenticular limestone with Crinoid fragments.

On the Kali near Gunji, violet siliceous and sandy shales reduced to less than 50 meters, seem to overlie directly the Garbyang series with a discontinuity. The lower part of the variegated Silurian is not present, although we are only 20 kilometers ESE of the upper Shiala section, and tectonically in the same zone. In Nepal, east of the Kali, the violet shales too are reduced to 100 meters and less.

A dense gray, somewhat nodular limestone of about 100 meters thickness which may be a special facies of the variegated Silurian sequence, was found on top of the Mangshang pass forming the Tibetan border (Pl. V, sect. 9), and at Dung (Fig. 107). This seems to have been known already by GRIESBACH, who regarded it tentatively as Devonian. It is, more probably, a special northern facies of Silurian.

The variegated Silurian is distributed far beyond the region we traversed in Kumaon. A great part of the so-called Zaskar range is formed of intensely folded and thrust variegated Silurian, which is found even as far as 20 kilometers northeast of the Tibetan boundary, where the glacial water is reddish from the triturated shales. Yet it is impossible to correlate our sections with those of Spiti according to HAYDEN. We have not met his basal Silurian conglomerate, nor does HAYDEN mention the conglomerate which we called after the Ralam pass, placed tentatively at the basis of the Cambrian.

The facies, in Kumaon, is that of a rather deep sea.

The Muth Series

In the region of Kuti, this series is over 1000 meters thick, and may be 800 meters as an average. It is mainly composed of brownish weathered quartzite with dolomitic layers, and capped by white massive quartzite. The name has been introduced by GRIESBACH and is accepted, since there is hardly a doubt of the correspondance with the Muth quartzite of the Spiti region. A special facies is the crinoid limestone of Lipu Lek.

The details were given in the local descriptions. The white top-quartzite not only varies in thickness from zero to nearly 200 meters, but is locally also replaced by dolomite (Kuti, Tinkar Lipu). The differences in thickness may be partly of primary origin. Partly, they are certainly caused by posterior denudation. The unconformity has been recognized long ago in Spiti, and is found again in a smaller degree on the Nabi peak in the Kuti valley (Fig. 82). This, how-

ever, was an exception, as far as we could judge. Usually, the upper edge of the Muth quartzite is conformable to the Kuling shale, in spite of the great gap of sedimentation.

The age of the Muth quartzite was regarded by GRIESBACH as Carboniferous, but according to HAYDEN's correction, it is upper Silurian. It could, however, also be Devonian. The latter age is accepted in the table of BURRARD and HAYDEN 1934 (8, p. 300).

The quartzites are devoid of fossils. Only in the limestone intercalation of Lipu Lek, Crinoids occur, and other fossils may be found (Fig. 74).

The Kuling- or Productus Shale (Permian)

The white Muth quartzite (Dravidian group) is usually conformably overlain with a sharp boundary by the well-known black Kuling shales (Aryan group). The basal conglomerate mentioned by HAYDEN from Spiti, has not been encountered in Kumaon. The great gap in Kumaon, thus may have chiefly been caused through absence of sedimentation during Devonian, Carboniferous and earlier Permian time. Within this great interval falls the volcanic activity in Kashmír, with the production of 2--3000 meters of trap.

The thickness of the Kuling shales is usually about 30—50 meters, but may be reduced to a few meters (Tinkar Lipu), or increase to about 100 meters (Lebong pass). In the eastern region (Lipu Lek, Kalapani), the lower part contains ferruginous (ankeritic to limonitic) limestone layers, rich in small brachiopods. A layer of 10 centimeters on Lipu Lek, two meters above the Muth series, may be called a lumachelle. Besides this rather shallow-water-type, the Kuling shale is but poor in fossils, and seems to be a rather deep marine deposit. This is confirmed by the appearance of the solitary beautiful ammonites of Lebong pass: *Cyclolobus Oldhami* WAAGEN and *Cyclolobus Walkeri* DIENER, which both are Upper Permian species (Phot. 21).

Kalapani is the only place where a lower stratigraphic horizon of the Permian was found (Fig. 69). The platy limestone may correspond to the "calcareous sandstone" of Spiti where it overlies the basal conglomerate and underlies the black shale.

The Triassic

Introduction

No division of the Tethys Himalaya has been stratigraphically worked out so much in detail as the Triassic. Its richness of fossils and its resemblance to the Alps was a special attraction to the Austro-German geologists, who partly were engaged by the Geological Survey of India, and have presented in their Memoirs the fundamental works on the Triassic of Kumaon: GRIESBACH 1891 (19, 20), VON KRAFFT 1900 (in DIENER), and DIENER 1912 (13).

V. KRAFFT, after having made special studies on the Triassic in Kumaon in 1900, unfortunately died in 1901, and left only some incomplete field notes. His material, including some manuscript sketches, together with the collection made by F. H. SMITH in 1899, was worked out by DIENER, who, through his former Himalayan experience, was the proper authority to treat this subject.

In spite of the long lists and careful determination of ammonites, however, it is, in the field, difficult to verify the paleontologic subdivisions. The sketches, though valuable, are without a scale; the fossils from different localities are partly mixed, and the exact locations are not mentioned.

To obtain a practical subdivision easily recognized, we propose the following main lithological divisions from below, in introducing two new names:

1. Kalapani limestone (after the famous place on the Kali)
2. Chocolate series (= Chocolate limestone of GRIESBACH and DIENER),
3. Kuti shales (after the village which is situated on them)
4. Kioto limestone (name from Spiti, introduced in 8, 1934).

1. The Chocolate Series (Lower Triassic)

Independently of former writers, we called this formation the "chocolate" on account of its characteristic brown weathering. It is, however, partly more a shale than a limestone. An analysis of a typical hard layer of chocolate weathering surface, together with a microscopic test, showed that the dark blue, fine-grained dolomitic "limestone" contains 50% or more of unsoluble substance (silica with clay), and 50% or less of carbonates (Ca Mg Fe). The black shaly parts deserve even less to be called limestone.

The localities where the basal contact is exposed are rare, or difficult of access. The best place we found is the "Castle-Hill" of Kuti (Fig. 88), where the lower coutact could be opened with the ice-axe, and is sharp and conformous.

The total thickness of the chocolate series in Byans (Kali-Kuti-region) is usually 30—50 meters. The subdivisions from below are:

a) "Castle Hill"-horizon, 3—5 meters, of streaky or nodulous impure ferruginous limestone with shaly layers, forming a light brownish projecting band on the cliffs, and rich of imperfectly preserved ammonites of the *Ophiceras*-horizon (see lists on page 117).

b) Middle division, 30 - 50 meters, a repetition of impure limestone, clay-iron-stone and shale with rare and badly preserved fossils.

c) Upper division, 3—6 meters, usually well defined, of chiefly shaly layers, forming a black band below the wall of the Kalapani limestone.

As already known, the chocolate series is of lower Triassic or Scythian age. However, the delicate question whether there is a slight omission of sedimentation between the Kuling shale of upper Permian and the Castle-Hill-horizon, remains unsettled. Also the exact age of the upper chocolate series has yet to be determined.

DIENER (1912) has already drawn the attention to the differences in thickness of the Lower Triassic from SE to NW. Whilst middle and upper Triassic are increasing, the Lower Triassic decreases towards Spiti from 150 to 40 feet. Perhaps it even sets out completely in NW Johar (Utta Dhura).

2. The Kalapani Limestone

Although lithologically appearing as a uniform division between the underlying and overlying shales, the Kalapani limestone represents the three great periods: Anisic, Ladinic and Carnic, as already recognized by DIENER. Ammonites are found throughout the limestone, though abundantly only in certain horizons. Even in the latter there are few localities permitting satisfactory collecting.

The top-layer excepted, the sections Fig. 70 and 89 show the thickness and lithologic subdivision.

Lithologically, the rock is characterized by its rusty to orange-coloured patches, made of ankerite, or ankeritic Calcite in tiny rhombohedrons. This facies strikingly resembles the Schiltkalk (Argovian) of the Helvetic Alps.

The thickness, usually 30—50 meters, varies from 15 to 60 meters. Not only is the Kalapani limestone a constant lithological member of NW-Nepal and Kumaon all along the Tethys-Himalaya, but according to DIENER it seems to continue over Painkhanda to Spiti.

Besides the ankeritic facies of dense non-zoogene ammonitic limestone of a bathyal character, the lower part of the Kalapani limestone has, in some parts, the aspect of a massive lumachelle. The broken shells, however, are fine and practically indeterminable.

At Kalapani, the middle part has been found in the shape of a hematitic layer rich of ammonites (Nr. 4 b in Fig. 70). The only good one that could be extracted from the wall *(Ptychites*

rugifer) is a leading Anisic species (Muschelkalk)[1]. The upper part must be Ladinic and Carnic, although "in Byans there is no evidence whatever of a representation of the ladinic stage" (DIENER p. 76). This already results from the occurrence of *Tropites subbulatus* in the top-layers of Kalapani, although in the section of Fig. 70 it is not a very rich fossiliferous horizon.

Abundant collections of a 3 foot horizon called Tropites limestone forming the top of the Kalapani limestone, were gathered in 1899 by SMITH and in 1900 by v. KRAFFT.

DIENER (13 p. 121—125) gives a list of not less than 155 species of ammonites of the *Tropites* limestone from Kalapani, Tera Gad, Lilinthi, Nihal and Kuti. The exact situations at these localities are not indicated, and the writer was not fortunate enough to find them on his traverses. Special time is needed first to find the rare, accessible places, where the contact of the Kalapani limestone with the overlying Kuti shales is exposed. On the SE side of Kuti, where this is the case, the *Tropites* horizon is lacking.

According to DIENER, the *Tropites* limestone contains 102 ammonite species peculier to this horizon. Amongst the remaining 53, "many important types point to the Carnic stage, and are indicative of a homotaxis with the Alpine zone of *Tropites subbulatus.* But a second faunistic element pointing to the Noric stage, is almost equally distributed in the *Tropites* limestone. Not less than 49 species of ammonites are either identical, or very closely allied with species from the Noric Hallstadt limestone or from the *Halorites* beds. A. v. KRAFFT was the first author to notice this strange assemblage of Carnic and Noric types in one single bed of limestone only three feet thick" (13 p. 126).

A further surprise is that, according to DIENER, the ammonites are not passage forms, but types of true Carnic and true Noric age.

In the same stratigraphic horizon, on Tinkar Lipu in Nepal (5200 meters), the rich fauna mentioned on page 111 was gathered. It is a gray sandy limestone connected with the underlying dark blue dense Kalapani limestone by a passage. While no indication in literature is found regarding the important question of stratigraphical relation of the "Tropites limestone" with the under- and overlying strata, we have here a positive indication that the Ladinic and Carnic stages must be represented by the upper part of the Kalapani limestone.

The fauna at the upper boundary of the Kalapani limestone of Tinkar Lipu in light gray sandy limestone is characterized by the abundance of very thick ammonites (Arcestidae) as well as by flat and sharp-edged forms attaining a large size.

Curiously enough, the genus *Tropites* is almost absent on Tinkar Lipu. According to Prof. JEANNET, the majority of the characteristic ammonites are Noric species. But there are also such characterizing the Carnic.

The *Tropites* limestone of Kumaon as well as the above mentioned one of Nepal are at the lithological boundary between the Kalapani limestone and the frankly Noric shales with slaty sandstones. The extraordinary abundance of individuals, aud the variety of Carnic and Noric ammonites together in the same bed, strongly recalls the famous horizon of Timor Island, discovered in 1904 by H. HIRSCHI, and described by J. WANNER and O. A. WELTER.[2] It is a pink limestone bed of 2 meters thickness, almost entirely made of well-preserved mixed fossils, of which 462 species of Carnic and Noric ammonites were determined!

A comparison of these two extraordinary horizons was already made by DIENER and is discussed again by WELTER. The problem of condensation indeed is the same, and is still wanting a solution.

[1] DIENER also determined 20 Muschelkalk-species collected by SMITH and v. KRAFFT from Kalapani and Jolinka (= Joling Kong?). The exact localities and stratigraphic horizons are not indicated.

[2] J. WANNER: Triaspetrefakten der Molukken und des Timor-Archipels. Neues Jahrb. für Min., Geol. u. Pal. Beil. Bd. XXIV, 1915, containing the monograph on the condensed ammonite layer by

O. A. WELTER: Die Obertriadischen Ammoniten und Nautiliden von Timor, 1914.

J. WANNER, Mesozoikum von Niederl. Indien, Leid'sche geol. Mededeelingen 1931.

Departing from the observations of condensed deposits of middle Cretaceous age in the Helvetic Alps, this problem was discussed by the writer in a general way[1]. There, not only a mixture of ammonites of otherwise different paleontological horizons was found, but also a change in the faunal composition from one place to another within the same stratigraphic layer. This is what also results in the Himalaya by comparison of the *Tropites* bed with that of Tinkar Lipu. To explain such differences by different life conditions or provinces is as unsatisfactory as to accept that all these hundreds of ammonites which normally are encountered far apart in the stratigraphic sequences lived together. For the Gault, in which the fossil moulds are phosphatic, the idea prevailing amongst the geologists is that of a "remaniement", i. e. of pseudo-condensation by redeposit of older horizons. But the above mentioned cases of condensation in the Himalaya and Timor are not related to hard phosphatic moulds, but to ordinary fossilisation in the limestones. Also, the fossils show no signs of re-deposition.

Besides the condensed Carnic-Noric layers, similar cases of other formations are known. WELTER (l. c.) compares with it the horizon of Balin, which furnished 66 ammonite species of mixed Callovian-Oxford types.

On Novaya Semlya (Archangelski Bay) the members of the XVII Intern. Geol. Congress were guided by A. A. PETRENKO[2] to a limestone layer of 0,5 meter thickness crowded with *Goniatites* and other ammonites of Viséan and Namurean types. Recalling the younger occurrence of Tinkar Lipu, the extremely thick and the extremely flat and sharp-edged types are lying there together.

Yet there remains the explanation tentatively mentioned already by DIENER, of extremely slow sedimentation. But even if so, the mixture of the fossils is not explained.

In consequence of the above observations, the Kalapani limestone is to be regarded as comprising not only the Muschelkalk, but all the three Triassic stages: Anisic, Ladinic and Carnic. DIENER (l. c. p. 129) has shown the rapid increase of the Carnic stage towards NW from Byans (Kali section) to Painkhanda (800') and Spiti, where it is given a thickness of 1550' = 470 meters, whilst in Kumaon it is supposed to be represented by the upper part of the Kalapani limestone of 30 meters at the most. In this sense the Kalapani limestone even as a whole is a somewhat condensed deposit.

3. The Kuti Shales (Noric)

Throughout the Tethys-Himalaya of Kumaon, the Kalapani limestone is sharply overlain with a series of more or less micaceous shales, 300—500 meters thick (Phot. 27, 28, Pl. XIII). In the NW, where it forms the Utta Dhura- (5300 met.) and Jayanti Pass (5600 met.), the upper part is characterized by regular layers of gray limestone, and the whole seems to exceed 500 meters.

The upper boundary towards the Kioto limestone is characterized by a passage zone with quartzite and oolite layers (Kuti, Chidamu).

Usually, fossils are rare. But on Tinkar Lipu, the magnificent fossils in black limestone flags mentioned on p. 111, and partly figured on Pl. XI were found. On account of complicated structure, the exact lithological horizon (Phot. 19, Pl. XI) could not be determined. It may originally have been 20—30 meters or so above the Kalapani limestone.

After a careful study by Prof. JEANNET, the fauna is frankly Noric. It contains numerous new forms, which shall be described in a special memoir of the Geological Survey of India. The facies is of a deep sea character.

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[1] ARN. HEIM und OTTO SEITZ: Die mittlere Kreide in den Helvetischen Alpen vom Rheintal und Vorarlberg und das Problem der Kondensation. Denkschr. d. Schweiz. Naturf. Ges. Bd. LXIX, 1934. — Stratigraphische Kondensation. Eclogae geol. Helv, vol. 27, 1934.

[2] The Novaya Zemlya Excursion. Guide book of the XVII Intern. Geol. Congress, Moscow 1937.

The ammonites confirm the former view of DIENER, who placed the "black shales with *Arcestes,* about 1000 feet" in the Noric.

4. The Kioto Limestone (Rhaetic)

This limestone series, which grows up from the Kuti shales by a passage zone with quartzite, is of wide extension in the synclines from NW-Nepal (Tinkar Lipu) to Garhwal. It is usually a dark blue, well-bedded limestone. Pretty oolites occur in the lower part. Ripplemarks were observed in the uppermost layers. Some bivalves excepted, fossils are rare in Kumaon, as compared with Spiti. The thickness increases from Kuti (150—200 meters) to the Garhwal boundary (600 meters), which is a distance from SE to NW of 75 kilometers. After HAYDEN and DIENER it is even 2600 feet = 800 meters thick in Spiti.

Only one distinct horizon within the limestone series was found, which may serve for subdivision: the problematics in the NW, 150—200 met. below the top (Phot. 39. Pl. XVI).

The age of the "gray limestone" (= Kioto) was regarded in a different way according to the various authors. HAYDEN (22, p. 73) took it as Rhaetic throughout. DIENER (13 p. 128), who had discovered the ferruginous oolite called "*sulcacutus* beds" erroneously speaks of a passage of the grey limestone "through beds of doubtful age into limestones of middle Jurassic age", having overlooked the discontinuity at the base of the oolite. The same view is maintained in Lit. 8 1934 p. 308.

According to our observations, there is no doubt that HAYDEN is right (although possibly the uppermost beds may reach into the lower-most Liassic). The lowest part is regarded by DIENER as upper Noric. New data are lacking to judge on this point.

The Laptal Series (Liassic)

This calcareous marine division is only known in the NW of Kumaon, from Kungribingri to Laptal, but seems to extend therefrom over Painkhanda to Spiti, according to HAYDEN and DIENER.

From the Kioto limestone to the Laptal series, the sediments were deposited without interruption, but wherever the Laptal series is wanting, there is a sharp discontinuity (Kuti valley, Chidamu-north).

The thickness at Laptal and surroundings is 60—80 meters. The facies characterized by repeated layers of lumachelle (agglomerate of shells) with small oysters, is of a shallow-water type in proximity of the former coast.

Besides *Cardium nequam* HEALEY (a species from the rhaetic Napeng series of Burma), the preservation of the fossils did not permit more than a generic determination: *Ostrea, Arca, Pecten, Lima, Astarte, Trigonia, Belemnites.* The presence of *Trigonia* excepted, which points to Liassic, our collection is not quite decisive for the determination of the age, but we may rely on the Liassic ammonites found by STOLICZKA farther northwest.

The Ferruginous Oolite (Callovian)

This minute, though most important index-horizon was discovered in 1895 by DIENER in the Chirchun area, and is usually referred to after its abundant *Belemnites* as the *Sulcacutus* beds. In the southeastern part of Kumaon it was found in 1899 by F. H. SMITH also in Byans (DIENER 13, p. 119) as a "constant and well-marked horizon on the top of the limestone series". The latter remark is an exaggeration. It was re-discovered by us on the Chaga pass east of Kuti, but is generally lacking in this region.

The maximum thickness of the ferruginous oolite described on p. 141 seems to be 3 meters. The ammonites collected from Laptal leave no doubt of the Callovian age. The upper and lower limits are microscopically sharp conformable discontinuities. Thus, the lower Dogger

(perhaps including the upper Liassic), is lacking. Where the ferruginous oolite is absent, the Kuti shales overlie the Laptal series or the Kioto limestone with a sharp conformable discontinuity.

The middle Jurassic, represented in Kumaon by 3 meters at the most, forms a great contrast to the Tibetan region east of Nepal, where HAYDEN (23, 1907) has established a great sequence of "highly fossiliferous limestones of middle Jurassic age".

The Spiti Shales (Portlandian)

This most famous fossiliferous horizon exploited since hundreds of years by the religious Tibetans, has been the object of the fine paleontologic monograph of V. UHLIG (1903). The fossils, having however been collected from the concretions washed down into the ravines, do not permit any stratigraphical subdivision. Furthermore, continuous outcrops of these soft black shales are scarce. A good region for further stratigraphic research may be the Kungribingri on the Tibetan boundary (Fig. 113).

The thickness of the soft black carbonaceous clay-shales varies greatly, apparently by stratigraphical and tectonical causes. On the eastern limb of Lahur anticline, the Spiti shales are only 80—100 meters thick, but accumulated in other regions (Kuti, north of Laptal) to many hundred meters. The Spiti shales were known from Spiti to NW-Kumaon, where they are the youngest series of the synclines, and have now been found again in the Kuti-Kali region.

The age is mainly uppermost Jurassic (Portlandian), though some ammonites are closely related to Berrias-forms. We thus have to consider the basal discontinuity upon the ferruginous oolite as representing the lower part of Upper Jurassic (Oxford to Kimmeridge incl.).

The detail-stratigraphy of the Spiti shales is still wanting. Nothing is known of the south-eastern continuation of the Spiti shales along Nepal. But on the north side of Kangchendjunga (Kampa Dzong), HAYDEN has identified the Spiti shales again in a tectonically similar position as that of northern Kumaon.

The fossils of our collection determined by Prof. JEANNET are:

Cephalopods

Belemnites (Belemnopsis) Gerardi OPPEL. Chaga Pass, Kuti, Chidamu and Laptal, frequent.
Oppelia (Streblites) substriata OPPEL, Laptal
Oppelia (Streblites) cf. *Griesbachi* UHLIG. Chidamu
Oppelia (Streblites) sphenodoma UHLIG and SUESS. Chidamu
Oppelia (Streblites) indopicta UHLIG.
Hoplites (Blanfordiceras) subquadratus UHLIG, Chidamu
Hoplites (Blanfordiceras) Wallichi UHLIG, Kuti
Hoplites (Blanfordiceras) sp. cf. *cerebrans* UHLIG, Kuti
Hoplites (Blanfordiceras) cf. *curvatus* UHLIG, Kuti
Hoplites (Blanfordiceras) cf. *latidomus* UHLIG, Kuti
Hoplites (Acanthoplites) cf. *subradiatus* UHLIG, Kuti
Hoplites (Acanthoplites) octogonus STRACHEY-BLANFORD (upper Spiti shale of Kuti)
Hoplites (Acanthodiscus) cf. *subradiatus* UHLIG, Kungribingri
Hoplites (Kossmatia) desmidoptychus UHLIG, Kuti
Hoplites (Neocomites) Walkeri UHLIG, Kuti
Hoplites (Neocomites) indicus UHLIG, Chaga Pass, Kuti
? *Hoplites (Berriasella)* cf. *Privasensis* PICTET sp., Chaga Pass.
Perisphinctes (Virgatosphinctes) similis UHLIG, Chidamu, Chaga Pass
Perisphinctes (Virgatosphinctes) cf. *biplicatus* UHLIG, Chidamu
Perisphinctes (Virgatosphinctes) cf. *Pompeckji* UHLIG, Kuti, Laptal
Perisphinctes (Virgatosphinctes) denseplicatus UHLIG
Perisphinctes (Virgatosphinctes) cf. *denseplicatus* UHLIG, Laptal
Perisphinctes (Virgatosphinctes) subfrequens UHLIG, Laptal
Perisphinctes (Virgatosphinctes) kutianus UHLIG, Laptal
Perisphinctes (Virgatosphinctes) cf. *serpentinus* UHLIG, Laptal

Perisphinctes (Virgatosphinctes) cf. *biplicatus* UHLIG, Laptal
Perisphinctes (Aulacosphinctes) cf. *tibetanus* UHLIG, Laptal
Perisphinctes (Aulacosphinctes) aff. *infundibulus* UHLIG, Laptal
Perisphinctes (Aulacosphinctes) linoptychus UHLIG, Chidamu
Perisphinctes (Aulacosphinctes) cf. *Chidamensis* UHLIG, Chidamu
Perisphinctes (Aulacosphinctes) cf. *Willisi* UHLIG, Chidamu
Haplophylloceras strigile (BLANF.) UHLIG, Kuti
Himalayites Seideli OPPEL sp., upper Spiti shales of Kuti, Chaga Pass
Himalayites hyphasis BLANF. sp., Kuti, Chaga Pass
Himalayites Hollandei UHLIG, Kuti

Pelecypods
Avicula spitiensis OPPEL, Kuti
Astarte sp., *Lima*?, *Aucella*?, *Nucula* sp. Laptal

Gastropods: some indeterminable moulds

The Giumal Sandstone (Lower Cretaceous)

This partly glauconitic series of sandstones with shaly layers gradually develops from the Spiti shales. Being found within Kumaon only in the northwest on the Kiogad, we refer to the description on p. 146. The thickness is estimated as 500—600 meters. This series also was called Lower Flysch by VON KRAFFT, and it is of Neocomian to Gault age, according to SPITZ.

The Upper Flysch (Upper Cretaceous)

As already described by VON KRAFFT (36, 1902), the Upper Flysch begins with red and green shales.

The main division is formed of black slates with sandstone layers and limestone flags with fucoids of the same facies and age as the ultrahelvetic Flysch of the Alps.

The highest and youngest folded series of the Tethys Himalaya in Kumaon are siliceous shales and chert with radiolarians (radiolarite), erroneously called tuff by VON KRAFFT. This occurrence points to a gradual deepening of the sea, apart from the Giumal sandstone, towards the end of the Cretaceous period (see description on p. 147).

The total thickuess of the Upper Flysch is estimated at 1000 meters or more.

No Tertiary deposits have been found in the Tethys Himalaya of Kumaon. The Quaternary will be described in a later chapter.

To the above review is added the table page 215 (see also the general sectiou Fig. 116).

The Gaps of Sedimentation

Reviewing the stratigraphic sequence above the Main Central Thrust, we must emphasize the fact that this enormous succession of 30 kilometers thickness, on the whole, is conformable, and that in consequence the great tectonical movement is younger than Cretaceous; this inspite of the great gap between the Dravidian and the Aryan groups comprising at least the whole Carboniferous and the earlier part of the Permian period.

The general conformity is the more surprising as in the NW Himalaya a distinct unconformity is known and considerable erosion had taken place in the interval, while in other districts (Kashmir) the huge Kanawas system of Carboniferous age has been deposited, followed by the Panjal volcanics (traps) of 5000—10000 feet thickness. The Dravidian-Aryan (= Muth-Kuling) gap also corresponds to the time of Gondwana glaciation (upper Carboniferous Blaini tillite), of which no more traces were found in the Tethys Himalaya. The distance from the ice sheet, after stretching the folds and thrusts, was 250—300 kilometers. It is true that distinct warm water deposits in the Tethys of the northern ranges only followed towards middle Triassic time.

The unconformity between the Dravidian and the Aryan group indeed was also recognized in Kumaon, although only locally (Nabi).

We have also drawn attention to an older apparent unconformity which we have tentatively placed at the basis of the Cambrian. In the two localities where the upper boundary of the Martoli series was exposed (Ralam pass and Gori above Milam), an unconformity below the Ralam conglomerate was observed, though part of it may be of posterior tectonical origin.

The above two gaps excepted, the entire series is completely conformable.

This however does not mean that the sedimentation was continous throughout. Frequently, small conformable discontinuities were observed, and among them are such ones that only could be traced by digging.

Such conformable discontinuities (disconformities) are:

1. The top of the Garbyang series on the Kali (Cambro-Silurian boundary)
2. The boundary of the Kuling shales to the chocolate series, which may represent a slight gap
3. Possibly, there is a slight gap between the Chocolate shale and the Kalapani limestone
4. The boundary between the Kalapani limestone (*Tropites* horizon) and the Kuti shales, in some places at least, is a sharp discontinuity.
5. A gap comprising part or the whole Lower Jurassic is extended throughout the region of our research in the Tethys-Himalaya. Where the Laptal series and the ferruginous oolite are present, the gap is doubled:
   a) Discontinuity between the Laptal series (Lias) and the oolite (Callovian)
   b) Discontinuity between the Callovian oolite and the Spiti shales (Portlandian)
6. Discontinuity between the red and the black Flysch at Malla Sangcha (possibly only local).

The nature of these small discontinuities, in contrast to the large ones caused by emersion, seems to be mainly, if not exclusively, caused by interruption of marine sedimentation (omission), number 1 perhaps excepted. The finest case of a submarine discontinuity is that related to the Callovian—a minute deposit of bathyal character, widely distributed though frequently lacking, and covered with another bathyal deposit, with a microscopically traced parallel boundary.

Facies and Tentative History of Sedimentation

Regarding the Tethys sediments in relation to their facies, we must first draw attention to the enormous thickness of the Dravidian group, while the Aryan group is rather thin as compared with the Alps. The Archean excluded, the Dravidian group is over 10 kilometers thick.

The Archean basis was a huge series of sandstones, clays and subordinate limestone layers. We recall the 9,4 kilometers of metamorphic sandstone of Pandukeshwar.

The Martoli series is a geosynclinal flysch facies. It was compressed, lifted and eroded.

The Cambrian forms a new cycle beginning with the coarse terrestrial Ralam-conglomerate, sandstone and dolomite, followed by the mighty second flysch-like series of Garbyang. The difference to the first cycle of Flysch facies is the more abundant lime and the green tuffaceous layers, the whole again forming a marine geosynclinal deposit of several thousand meters.

The "Lower Silurian" (Ordovician?) in Spiti, according to Hayden, begins with another basal conglomerate. This third cycle of sedimentation is again followed by subsidence. The conditions changed from variegated clay to calcareous sandstones with brachiopods until the marl and dense lime was precipitated under rather deep sea conditions. But then followed an intense importation of fine quartz sand from the coast (Muth series).

In Carboniferous time the Muth quartzites were erected to a land-surface of little inclination, sufficient only to be locally eroded (Basal Permian conglomerate in Spiti).

During the later part of the Permian, the Dravidian rocks were again drowned, and black carbonaceous clay was washed into the sea. A rapid deepening is indicated by the dis-

appearance of the basal *Productus* lumachelie and the solitary appearance of the beautifully preserved *Cyclolobus* in the upper part.

The marine conditions persisted into Triassic time, though during short intervals the sedimentation ceased.

The chocolate series must have been deposited under an increase of silica and iron which points to rather cold bottom currents.

In Muschelkalk time follows the interesting facies of the Kalapani limestone. Although being partly made of broken shells, it is mainly a dense non-organic precipitate. The ankerite patches of the concretionary deposit were formed by diagnesis. The fossils, almost exclusively ammonites, are of a bathyal type and prove that the limestone of 20—50 meters thickness must represent the total deposit of the Anisic, Ladinic and Carnic periods, which in Spiti and in the Alps are largely developed. The slowness of deposition is even more accentuated by the 1—2 meters top-horizon, the *Tropites* limestone and the equivalent of Tinkar Lipu, which are a condensed product of Carnic and Noric age. The problem is discussed on page 208. This top-horizon is locally represented by a discontinuity (Kuti SE) caused by a complete interruption of sedimentation.

Meanwhile the marine conditions have changed, and the new argillaceous sediment became more rapidly deposited (Kuti shale). Sandy material was washed into the Tethys sea until a new phase of calcareous precipitation began with beautiful non-organic oolites. The lime was accumulated on a rather shallow sea bottom under slow subsidence. This is shown by the fauna: thick-shelled bivalves *(Megalodon)* and corals *(Lithodendron)*. The occurrence of ripplemarks in the upper layers is a rare case in pure limestone.

The passage to the Laptal-lumachelle not only confirms the above view, but proves by its myriads of shells the shallow-water conditions near the shore.

But the lumachelle was not regularly distributed. Even within a few kilometers it does not occur. In its place is the discontinuity already described.

The lack of erosion shows that there was but a short and local emersion, if any at all had taken place.

After and during the interval of omission followed a new uniform subsidence and the slow calcareous deposit of the ferruginous oolite, with its Belemnite- "battlefield". It is regarded as a mainly chemical sediment.

After another period of non-deposition on the deep sea bottom followed a third invasion of carbonaceous clay with silica. The numerous ammonites lived on the deep muddy ground of the sea, some attaining great age and huge size, though they are not as numerous as might be suggested from the collections. They are indeed collected from ravines where they are concentrated, but rarely found in situ.

The marine conditions prevailed when on the eve of the Cretaceous period more sand was washed into the sea, and glauconite was formed in the cold waters. Particles of basic igneous rocks where then washed into the sea from the Tibetan side. By change of current which warmed up the water, the variegated marls and limestones of the upper flysch were deposited. Then followed a rapid geosynclinal deepening as a harbinger of the great tectonical movements. The black flysch was deposited, followed by red and green silica deposit of great depth as real radiolarian oozes. The thickness of this limeless chemical deposit of 200 meters and more suggests a rather long calm period towards the end of the Cretaceous, and a depth of the ocean bottom of at least 5000 meters.

What happened then is not yet clear, because no younger sediments are known following the radiolarian deposits, except that younger basic igneous rocks (peridotite) were injected into these deposits below the deep sea ground. During this late Cretaceous time when the Tibetan trough of negative gravity anomaly in the northern part of the Tethys became

injected, the greatest igneous flows known on our globe were extruded in Gondwana land: the Decan trap, in a counterbalanced zone of positive gravity anomaly [1].

Then followed in post-Cretaceous time the great tectonical movements in the Tethys region, ending with the uplift of the deep sea bottom to 5000 meters and more, which is a vertical movement of more than 10 kilometers.

The Tibetan-, Raksas-, and Transhimalayan Facies

It is DIENER's and VON KRAFFT's merit to have drawn attention to the complete difference in facies of the normal Himalayan folds of north Kumaon to that of the exotic region of the Kiogar- and Chirchun region, to which the term of Tibetan facies was applied. This clear distinction is not followed in BURRARD and HAYDEN's Geology of the Himalaya (8, 1934) in which the "Tibetan Zone" comprises mainly the Himalayan facies and corresponds to the Tethys Himalaya of AUDEN's and our understanding.

Since the Kiogars are not exotic blocks thrown over by volcanic eruption, the complete difference of facies alone would be sufficient proof of thrusting on a long distance. We refer to the summaries after the detailed descriptions.

Beyond the Kiogars, however, follows the Chilamkurkur range of a facies which, passing underneath the exotics, seems to be in direct relation to that of the Tethys Himalaya. More eastward, the change of facies, connected with short distance thrusting, is met before reaching the overlying flysch with its exotic blocks: the thrust sheet following towards northeast upon the typical zone of the Tethys Himalaya shows a change in facies, the Silurian being overlain by a Mesozoic series with middle Jurassic Belemnites and a thick series of Spiti shales (GANSSER, Pl. V). The main difference between the Chilamkurkur-Raksas facies and the typical Himalayan facies seems to be the large development of shaly Jurassic sediments, similar to the region north of Kangchenjunga in the east, described by HAYDEN (23).

A total difference in facies is found again in the Transhimalaya, where the whole sedimentary series from Pre-Cambrian to Cretaceous incl. is suddenly lacking, and the Tertiary Kailas conglomerate transgresses over granite [2].

Petrologic Review

(by AUG. GANSSER)

Only the crystalline rocks are here reviewed.

I. Metamorphic sediments (Para-Rocks)

The original sediments of this class have been mainly sand and clay with frequent intermediates, partly also calcareous deposits.

The most uniform rock is the quartzite, even within the highly metamorphic zone. Only when the sand was argillaceous, the typical minerals of the crystalline schists were formed, according to the grade of metamorphism. Examples of meso-metamorphic rocks derived from impure

[1] In the Charts I and IV of GLENNIE's valuable publication (18) the main Trough line or "Bottom of Trough" is drawn along the upper Indus and Sutlej, just where we consider the root of the Exotics. This line, although corresponding to our geological research seems to be merely hypothetic, as well as the peculiar "3rd Crest", which crosses obliquely the total width of the Himalaya over a distance of 800 miles within which no observations are indicated.

[2] The Kailas conglomerate is regarded as Later Eocene by HENNIG (32), and is certainly younger than Cretaceous. The sandstone contains fragments of radiolarian chert of the flysch (H).

Stratigraphy of the Tethys-Himalaya in Eastern Kumaon and NW-Nepal (by ARNOLD HEIM and AUGUST GANSSER 1938)

〰〰 unconformity ——— conformable discontinuity

Group	Period	Age	Stratigraphic division	Average thickness (meters)	Typical localities	Facies	Fossils
Aryan Group		Pleistocene	Glacial and Interglacial	200	Kali; Alaknanda	Moraines, gravels, varves	
Aryan Group	Cretacic	Upper Cret.	Upper Flysch	1000	Kiogad	Siliceous shales, chert Black shales Red and green marls	Radiolarians *Chondrites intricatus*
Aryan Group	Cretacic	Lower Cret.	Giumal sandstone	600	Laptal–Sangcha	Glauconitic, calcarous and siliceous sandstone and shale	rare Pelecypods
Aryan Group	Jurassic	Portlandian	Spiti shales	100	Kuti; Laptal	black shales with siliceous fossiliferous concretions	well-known rich cephalopod fauna
Aryan Group	Jurassic	Callovian	Ferruginous oolite	1.5	Laptal; Kuti	dense limestone and shale with ferruginous oolite grains	Belemnites and Ammonites *Reineckeia, Macrocephalites*
Aryan Group	Jurassic	Liassic	Laptal series	60	Laptal; Kungribingri	Lumachelle, brown limestone with shales	Pelecypods, Belemnites
Aryan Group	Triassic	Rhaetic	Kioto limestone	500	Kuti; Chidamu	Grey limestone	Pelecypods
Aryan Group	Triassic	Noric	Kuti shales	500	Kuti; Uttadhura	Black, partly micaceous shales	*Arcestes* rich fauna of Tinkar Lipu
Aryan Group	Triassic	Carnic Ladinic Anisic	Kalapani limestone	50	Kalapani	Dense blue concretionary limestone with ankerite patches	155 Ammonites of *Tropites* zone, rich fauna of Tinkar Lipu, *Ptychites rugifer*
Aryan Group	Triassic	Scythic	Chocolate Series	50	Kuti Valley	Ferruginous, siliceous limestone and shales	Ammonites of Kuli-Castle: *Ophiceras, Meekoceras*
Aryan Group		Permian	Kuling Shales	50	Lipu-Lek; Kalapani	Black shales with ferruginous layers	*Productus, Cyclolobus*
Dravidian Group		Carboniferous				Great Gap Local unconformity	
Dravidian Group		*Devonian?*	*Muth series*	800	*Kuti*	*Quartzite and dolomite*	Crinoids in limestone of Lipu-Lek
Dravidian Group		Silurian	Variegated Silurian	700	Zaskar range	Shales and limestones with Crinoids	Crinoid fragments ind.
Dravidian Group		Ordovician	Shiala series	500	Shiala Pass	variegated shales and calcareous sandstones	Brachiopodes and Trilobites
Dravidian Group		Cambrian	Garbyang Series	4.500	Garbyang	sandy calcareous shales with chloritic layers	flat Gastropods
Dravidian Group		Cambrian	Ralam Series	800	Ralam Pass	Dolomite, quartzite Basal conglomerate	
Dravidian Group		Algonkian	Martoli series	5.000	Martoli–Milam (Gori Ganga)	Phyllite with quartzite (flysch facies)	
Dravidian Group		Archean	Vaikrita; Paragneiss, Quartzite	15.000	Kali river; Alaknanda above Joshimath	originally sandstone with clay and limestone	

sands are the kyanite-bearing quartzite of the Kali and the kyanite-staurolite bearing quartzite below the gneiss of Darjeeling. More argillaceous sands have produced sericite- and garnet-quartzite. The latter, frequently associated to gneiss (Almora), however, are usually of the epi-type.

Frequently, the quartzites are interbedded with sericite-garnet schists and appear by their uniform mineral content to be less metamorphic. Also different rock types may be formed by selective metamorphism under similar physical conditions.

Under higher pressure, the mixed sediments were transformed to gneiss (paragneiss). These rocks with feldspars frequently pass into the common mica schists and usually cannot be separated at once in the field (Almora-Binsar). The usual paragneiss is a sericite gneiss of epi-type. Less frequent is a real muscovite-biotite gneiss. As meso-kata-gneiss are regarded the mighty biotite-psammite gneisses of the Kali, Gori, Pindar and Alaknanda gorges. Then follows the complex kata-gneiss connected with the limesilicate marbles which may be called calcsilicate gneiss (Kali, Pindar, Alaknanda).

II. Mixed Rocks (Migmatites)

To this category belong the complex and varied injection gneisses which were frequently found in the Central thrust mass together with biotite-psammite gneiss. All possible types of passage occur, from the slightly injected paragneiss to the granite gneiss, which only contains little remaining material of sedimentary origin.

While in the Darjeeling region the injection gneisses develop gradually out of the sedimentary or para-rocks, they occur more frequently in the Central Himalaya (Kumaon) in the shape of layers or zones between other gneisses. They were encountered at the basis of the calc-silicate zones.

As a basic para-rock, although very subordinate, may be mentioned the para-amphibolite (Khela).

III. Igneous Rocks

A. Acid Igneous

Older acid Igneous Rocks are mainly orthogneisses in the shape of augengneiss, rich in muscovite, biotite or both, but rarely with biotite alone. They are usually easily distinguished from the true para-rocks, but not so of the injection gneiss.

The augengneiss forms well-defined layers within the southern crystalline part of the great thrust sheet, where they are usually conformable to the paragneiss and mica schists. (Bari Chhina, Binsar, Ranikhet.)

The true granite of Almora also, as a whole, is interbedded in the schists without cutting across them. At the contact of the granite as well as of the orthogneiss with the schists, no distinct contact metamorphism could be observed. It must have been obliterated together with the primary unconformities by repeated tectonical influences. Inspite of this, the ortho-rocks must be regarded as intrusions in the para-rocks, and thus are younger than the latter. This is confirmed by a finer grain along the border of the ortho-rock, observed at Almora and Ranikhet. In no place a transgression of para-rocks over ortho-rocks was observed.

Similar conditions to the great masses of ortho-gneiss are found in the crystalline Penninic thrust folds of the Alps.

The age of the massive hornblende granite of the Kailas is not yet determined, except that it is regarded as pre-Tertiary. According to its minerals, it is rather older than the younger himalayan tourmaline granite.

Younger acid Igneous Rocks. To this category belong the white tourmaline granite, and the accompanying pegmatites and aplites which are unknown of the older intrusions (augengneiss). In contrast to the older acid igneous rocks, these younger rocks break across the stratified and folded schistose rocks and are of completely directionless structure. Inspite of this, they are considered to be older than the main thrusting movement. Forming part of the great root zone, they seem to have been transported passively.

The younger granite has been found in the Nampa- and the Badrinath-group. The corresponding dykes of pegmatite and aplite were met with on all our traverses of the central crystalline zone (Kali, Gori, Pindar, Alaknanda), always in connection with calcsilicate marbles and paragneiss, the strata and folds of which are crossed. The last or uppermost dyke (aplite) was found in the Garbyang series (Cambrian) of the Nampa Valley.

B. Basic Igneous

Old basic Igneous. Most of these rocks are altered diabase in the shape of amphibolite or only chlorite schist. They are conformably intercalated in the sedimentary rocks or between these and gneiss, and tectonically behaved like ordinary stratigraphic layers, though originally intruded in sills. No transverse dykes were found. These sills are younger than the limestone and quartzite (Krol-Tal) but older than the main folding and thrusting.

As was the case with the old acid intrusions, no distinct contact metamorphism was found. Only a diminution in the size of the grain towards the border was observed in several cases. A striking fact is the frequent occurrence of the green basic rocks at the contact of gneiss and quartzite below the thrust plane (Pl. II, Sect. 4b and III, Sect. 6c), and between limestone and quartzite. By their conformous intercalation they recall somewhat the ophiolites of the Penninic Alps.

Younger basic Igneous. This category of Cretaceous to post-Cretaceous rocks was only encountered in Tibet and its borders.

Besides the porphyritic extrusives in connection with the Kiogars and the exotic blocks, which are older than the flysch and have been described in detail, the youngest igneous rocks encountered must be mentioned. They are younger than the upper Cretaceous flysch and of vast extension in Tibet. The main type is a peridotite (enstatite-peridotite of Jungbwa and Shib Chu) which is partly transformed to serpentine, especially at the smaller occurrences (Balchdhura, Kiogar 5). Less abundant is the syeno-diorite of Amlang La, which breaks across the upper Cretaceous flysch limestone. Although the peridotite may be younger than part of the main tectonical displacement, it still shows signs of tectonical influences.

Tectonics

(see map and generalized section)

The Ganges Plain

Flying at an elevation of 3000 meters from Allahabad towards south-east, the structure of the Aravalli Range is beautifully visible, especially on account of the hard quartzites which project in the shape of sharp crests. The whole folded, then truncated old range is directed north-east, at a right angle towards the Himalaya. But 200-300 kilometers before reaching the Siwalik border, the rejuvenated old range disappears below the Gangetic alluvial plain. It has been known for a long time that its gravels and sands are not merely a superficial deposit. Deep borings have shown it to exceed many hundred meters, and after the geodetic survey of India, Oldham (53) calculated the depth of the "Gangetic trough" along the outer edge of the Himalaya to be 15000—20000 feet deep, the maximum depth being 10—30 miles away

from the mountain border. It is in this still downwarping geosynclinal fore-deep (Vortiefe) that the earthquake of Bihar, of January 15th 1934 caused the greatest destruction (over 10000 people killed). The epi-centre, according to GRAAF HUNTER[1] and AUDEN[2], corresponds approximately to the zone of greatest underload. From this extra-Himalayan centre, however, the Siwalik region and the Lower Himalayan ranges of Nepal were shaken too. But no displacement could be observed along the Main Boundary Thrust where it is exposed near Udaipur Garhi. This earthquake was preceded by a similar shock in an approximately coincident area. Although the movements on the surface were not decidedly in one direction, these earthquakes must be regarded as the result of a sudden expression within the persisting subsidence during geological length of time. This is already seen from the actual topographic depression with swamps. Indeed, the subsidence must be faster than the accumulation, despite of the enormous quantities of material brought down by the yearly monsoon floods from the ascending Himalaya.

Besides this fore-deep type of earthquakes, there seems to have been another one in a more north-westerly region. MIDDLEMISS (Records XXXII, 1905) described the earthquake of Kangra which killed 20000 people on April 4th 1905. According to his statements, this earthquake originated from a geotectonic movement along a line of 60 miles, from Kangra to Dehra Dun-Mussoorie, and was "apparently connected with a reversed fault intimately bound up with the structural history of the Himalaya".

The Siwalik Border

The resemblance of the Siwalik facies to that of the Gangetic Alluvium has been recognized already by MEDLICOTT in 1868 (40). Similar conditions of deposition are thus assumed for the southern border of the Himalaya during the earlier Pleistocene and later Tertiary period, when the fore-deep was situated north of the actual trough. The thickness of the Siwaliks in the region of the Ganges, according to MEDLICOTT, is 15000′ to 16500 , figures which correspond to those of the Subalpine Molasse. DE TERRA (1934) gives a figure of 20000′ for the Upper Siwaliks only in the north-western region.

Such accumulations obviously did not cause an isostatic equilibrium of the earth's crust; on the contrary they have been made possible by tectonical down-warp balanced by up-warp of the adjacent regions. This is in complete agreement with GLENNIE (18, p. 20).

GRABAU, HUANG, DE TERRA and TEILHARD[3] drew attention to the general phenomena of Central Asiatic tectonics regarding the migration of fore-deeps: erection of a mountain range, deposit of its talus on the border, followed by a new tectonical advance which envolves the former detrital accumulation into the mountain range until the consolidated, folded and overthrusted former Piedmont gravels are again eroded, and a new fore-deep is developed (as is actually the case in the Himalaya).

The young age of deformation of the Siwaliks in the NW is well-known from the fact that Pliocene to Middle Pleistocene conglomerates are strongly dislocated and even overthrusted (for instance Miocene over Pleistocene at Kalka, Simla railway). The Middle Pleistocene "Karewas" of Kashmir Valley, with its modern plant contents and human implements, was lifted up to the Pir Panjal range, as already recognized by GODWIN AUSTIN (SAHNI, 55)[4].

[1] Nature, Vol. 133, p. 236, 1934.

[2] J. B. AUDEN and A. M. N. GHOSH, Preliminary Account of the Earthquake of January 15th 1934 in Behar and Nepal. Records of the Geol. Survey of India, Vol. 68.

[3] P. TEILHARD DE CHARDIN; The Significance of Piedmont Gravels in Continental Geology. Rep. of the XVI Intern. Geol. Congress, Washington 1933, Preprint 1935.

[4] Dr. HELLMUT DE TERRA who is preparing a new volume on the Pleistocene of the Himalaya, kindly informs me that the boulder conglomerates of the Chenab-fan (second glaciation) are lifted more than 1500 feet, and that even the terraces of the third and last glaciation are dislocated, especially at Jammu.

The time-interval between the age of the advanced Anthropoids (Pliocene) and the appearance of tool-making man (such as *Pithecanthropus* and *Sinanthropus* of Middle Pleistocene, great Interglacial), is tectonically characterized by the main Himalayan uplift (DE TERRA, 63).

What seems to be a new conception derived from our observations of the border zone, is concerned with the Main Boundary Thrust. This border line was found to be an old surface of erosion, over which the older Himalayan formations were thrust, and through the gaps of which they advanced over the plane in huge arch-shaped waves. It is the same phenomenon discovered thirty years before on the northern border of the Alps (see Fig. 6 and 13). This erosion and the advance of the thrust masses are younger than the Upper Siwalik conglomerates and must thus have occurred mainly in the Plio-Pleistocene period.

It would be a fascinating task to make a comparative study of the contact all along the interior Siwalik-border. (The older publications are insufficient to judge on such modern questions.)

The Lower Himalaya NW of Kumaon

The huge thrustfold—the greatest that is known on our globe—encountered in the region of Darjeeling and Sikkim and comprising also the section of Mount Everest (Pl. I and Fig. 4, 15) changes its frontal shape in the region of Nepal and farther northwest. The amplitude of thrusting is, however, not diminished.

Already AUDEN's sketch of Katmandu (4, p. 142) shows no longer the reversed series with Darjeeling gneiss on the top. Even more complicated is the structure of Kumaon. North-west of the Ganges almost nothing is known of the interior thrust zone for a large distance, while the border region is being worked out by the Geological Survey of India and is in parts already mapped in detail. Special attention was naturally paid to the region of Simla. After PILGRIM and WEST (Memoirs Vol. LIII 1928), the existence of at least 4 superimposed thrust sheets can hardly be questioned any longer, the whole overlying the parautochthonous folds of Simla slates and Nummulitic.

The continuation of the Krol Belt towards the Ganges is worked out by AUDEN whose fine observations are of first importance for a comparison with Kumaon (3, 1934 and 5, 1936.) According to AUDEN the border region between Mussoorie and Simla also consists of several thrust-sheets piled upon each other; but the most important tectonic observation is the establishment of an autochthonous window at the basis of these thrust-sheets, 6—8 kilometers north-east of the Main Boundary Thrust. It was followed from Mussoorie to the Ganges. Mr. J. B. AUDEN was kind enough to guide us through this region where we completely confirmed his views.

The Lower Himalaya of Kumaon

South-east of the Ganges, the crystalline rocks form a great doubled syncline, thrust over Krol and Tal, the latter being thrust over the Siwaliks. This at least must be deducted from the map of MIDDLEMISS (42, 1887). No later survey was made of this most interesting region where the crystalline rocks project nearest to the plain. The preservation of such a rather high crystalline thrust mass must be caused by an axial pitch towards SE on the Ganges. The autochthonous window of Tehri, with Simla slates covered by Eocene, seems to disappear definitely east of the Ganges below the thrust-sheets. The syncline may be the continuation of the one south-east of the Malkot window in Tehri, where the higher thrust sheets are weathered away.

We shall now review the different tectonical zones from the "Main Boundary Fault" towards the interior, in the region which we traversed, with our tectonical interpretations of Plate 1 at hand.

1. At Naini Tal the Krol Belt is encountered as a continuation of that in the border region of Simla. From the China Peak, 2600 meters, the rounded limestone mountains can be seen for a long distance towards NW. The thrusted syncline of Naini Tal recalls the border syncline of Mussoorie. The north-eastern limb, however, is stratigraphically different because of its enormous thickness of Infrakrol (?) shales. The contact to the next zone at Bhowali is not well exposed and needs further study.

2. The quartzite of Bhowali, with diabase and limestone forms a peculiar anticline with vertical layers on the axis. Underneath an autochthonous anticline is supposed. The Bhowali zone is thrust by gneiss and schistose quartz porphyry (Ramgarh), upon which again follows the sedimentary series of uniform north-eastern dip.

3. After crossing a series of phyllites and quartzites which might be reversed, the wide crystalline zone of Almora is reached. There, a huge mass of well stratified mica schists with quartzites, injected orthogneiss and granite, forms a vast syncline. The axis strikes normally WNW from north of Almora to north of Ranikhet. The wide crystalline syncline of the Dudatoli massive, mapped by MIDDLEMISS in 1887, is the continuation of it towards north-west. At Almora the synclinal axis pitches gently towards WNW. The Almora zone, with a width of 25–50 kilometers, is bordered on both sides by thrust contacts. The one in the north, regarded by MIDDLEMISS as a straight fault, is well defined at Dwarahat and Diwali Khal (Pl. I, Sect. 3 and Fig. 39).

Obviously the lower boundary at Kanari China is the same as that one of Dwarahat, whence it was followed beyond the Diwali Pass, thus altogether over 70 kilometers. All along, where the crystalline stratification was visible, the dip is towards SW.

4. North of the crystalline Almora-zone and underneath it appears a complex sedimentary zone of complicated folding and minute warping, with quartzite and subordinate phyllite, connected with limestone and dolomite. The first zone of Badolisera-Barichhina-Someshwar (Ba) seems to continue at Chaukhutia (C). The limestone is partly non-metamorphic and resembles Krol. If it is Krol, the large overlying quartzites must be Tal. The greatest complications are met with between Kanary Chhina and Askot in the East, and along the Alaknanda in the NW. The details are shown in the descriptive text and in the sections. Frequently the strata are vertically erected. Along the Alaknanda green, metamorphic, igneous rocks are most conspicuous within the sedimentary sequence. Though the series seems to be several times repeated, nicely traceable folds are an exception, while obscured scaly minor thrusts seem to be the rule. The section Karnaprayag-Chamoli is one of the most intricate and disappointing one on account of discontinued outcrops and changes of strike.

5. Within the folded and twisted sedimentaries, two subordinate crystalline outliers are distinguished, the one of Askot-Thal (A) and that of Baijnath (B). Both are of a synclinal position. The north-easterly dipping of gneiss over quartzite with chlorite schists is nicely exposed on the road to Kausani (Fig. 34).

The outlier of Baijnath begins at Bageshwar in the form of a narrow filling of a normal quartzite-syncline. The pitch of the syncline to WNW explains the broadening towards the valley of Baijnath, while the extreme northern deviation from Dewali to Wan is the expression of a regionally twisted strike. The connecting tectonical bridge at the pass between Wan and Kanaul with the Main Central Thrust is somewhat hypothetical.

Towards the Almora zone, no crystalline bridge is found as far as we could observe, but there may exist one beyond our field of research. The former connection is indubitable. The gneiss at Kausani is of the same type as that of the basal zone from Binsar to the Kosi river, where the sedimentary zone between is narrowest.

We must also mention other small crystalline zones intercalated in quartzite in the shape of minor thrust sheets, one on the Kuari Pass (Fig. 37) and two on the Alaknanda, below and above Chamoli. The latter locality is the only one where sediments were found superposed on gneiss

and mica schist. Since they consist of quartzite, not much can be deducted regarding the origin of this synclinal Chamoli thrust sheet. It seems, however, safe to say that it can only be of secondary importance and may derive from underneath the Great Central Thrust (Pl. IV).

6. The great calcareous zone of Tejam is the largest and the most interior tectonical zone of the Lower Himalaya. Obviously it continues towards NW underneath the quartzite frame in the shape of pseudo-windows at the Nandakini river and again at Pipalkoti on the Alaknanda.

The structure, on the whole, may be called an anticlinorium consisting of several anticlines of normal and of fan-shaped type. The strike is so much twisted in places that it is not yet possible to coordinate the single folds from one transverse river section to the next. The limestones and quartzites could be followed with some interruptions over a distance of nearly 150 kilometers. They are of an enormous thickness. Thus the river north of Tejam exposes over 5 kilometers of limestones and dolomites, interbedded with slates of astonishing regularitiy (Fig. 33). The corresponding, regularly dipping, mainly dolomitic series of the Upper Sarju, according to A. Gansser (Pl. III) is about 3 kilometers thick. The main quartzite, of great thickness again, seems to overlie the limestone normally, so that once more the question arises whether we have the Krol-Tal series before us, although the carbonates on the whole are more transformed to marble than in the outer zones. At the mouth of the Birehi north-east of Chamoli, the anticlinal limestone is sheared off (Pl. IV, Sect. 7a). The sheets of gneiss between the sedimentaries are difficult to explain. They might be lower offshoots of the main thrust, coming down from the NE. The definite understanding of such tectonical problems would require thorough mapping, based on improved topography of large scale.

The autochthonous window NW of the Ganges, with Simla slates and transgressive Eocene, is so totally different from the sedimentaries of the Lower Himalaya of Kumaon that the latter cannot be regarded as autochthonous, but must be part of lower thrust sheets, similar to the great crystalline Silvretta sheet of the Alps which covers the lower sedimentary thrust sheets (Fenster of Engadine, Prätigau).

The Crystalline Central Zone

On all our traverses, on the Kali (Pl. II), on the Gori Ganga (Pl. III), at Girgaon (Fig. 33), north of Loharket (Pl. III), on the Kuari pass (Fig. 37) and on the Alaknanda (Pl. IV), the crystalline central zone overlies the sediments of the Tejam zone with quartzite as its uppermost division. Only on the Kali the quartzite sets out locally and seems to be sheared off. Apart from subordinate intermediate layers which might be regarded as reversed sediments, the contact is a nicely traced thrust, of a gentle dip (20—35°) towards north (Gori Ganga), north-east (Kali, Joshimath) and nearly east (Nandakna). The basis of the huge crystalline body is formed by mica schists with ortho-gneiss.

On the whole, the stratification of this crystalline body is remarkably uniform, some changes in the strike from W to NW excepted.

On the Kali, the central zone is subdivided by the sedimentary zone of Sirdang (Pl. II), upon which gneiss of the Darjeeling type is thrust at an angle of 45—50°. As seen from an elevation of 3000 meters (Fig. 60—61), the mountains towards NW show such a regular stratification that this zone must continue to the Dhauli Valley. The further continuation is unknown. No indication of the zone of Sirdang is left on the Gori Ganga. It is possible that this zone is connected with the sedimentary region of Mathkot (Mansiari), a region we did not visit. In that case, the lower crystalline thrust mass of the Kali (Khela) would be a separate thrust mass ending towards west on the Gori Ganga, and our tectonical interpretation of plate I would have to be altered accordingly.

The passage of the Archean crystalline mass of 10 - 20 kilometers thickness into the normally

overlying phyllites and quartzites of the Martoli series has been described locally and petrologically. The dykes are "dying out" in the Martoli series. The last dyke was seen by A. GANSSER on the eastern peak of Nanda Devi. In this region, the Martoli series is folded. The top of Nanda Devi 7820 meters, the highest peak of the Central Himalaya, is synclinal, while its north-eastern slope is formed of an anticline.

Much stronger folding is found on the Alaknanda, not only in the sedimentary cover, but in the crystalline body itself. The syncline of Badrinath with its vertical axis forms a real fan, of an abnormal WSW strike, while the anticline on its north side is normal and upright (Pl. IV). Such changes in the strike over more than a right angle are thus characteristic not only of the Lower Himalaya, but also of the Crystalline Central zone of deepest tectonical origin. It may be the last reminiscence of the old Aravalli-substructure.

The widening of the Crystalline Central zone in the region of Badrinath and the divergences of the strike are in connection with the almost sudden extension of the intrusive tourmaline-granite which dominates the magnificent mountains of the Badrinath-Kedarnath-Gangotri-Group, including the marvellous peak of Sonero Parbat (AUDEN).

The Thrust Zone of the Tethys Himalaya

Obviously, the great thrusting movement only was possible at the depth before the thrust sheet was dissected by erosion. It thus must have been followed by a regional vertical (radial) movement. While thrusting may still continue in the border zones, we have found no indications of continuing horizontal displacements in the interior zones, while the erection certainly has not yet come to an end.

The greater part of this zone was mapped in about 1:250000 and published with a detailed description by GRIESBACH in 1891. This work, though remarkable for his time, proved to need ample corrections. There is not only the one thrustfold found by GRIESBACH above Kalapani. The characteristic feature is repeated thrusting from Tibet towards SW, while vertical faults hardly exist.

Departing from the Central Crystalline Zone, the huge succession of the Martoli-, Ralam- and Garbyang series seems to form a normal cover. At least, no indications of major repetitions were found. Only on the upper Gori Ganga, the Ralam conglomerate and the Garbyang series are doubled, the upper series with the basal conglomerate apparently being thrust over the lower one.

The upper Garbyang zone of the Gori is normally overlain by the Ordovician-Silurian series, which seems to be doubled again by a secondary thrust at Dung.

In the south-east, the lower divisions seem to be normal up to the Silurian, where folding occurs. In the NW, the lowest divisions are more thrusted, while the upper ones are more normally folded, both being the result of the same push from the Tibetan side.

Beginning on the Kali, the first thrust zone is found SW of Kalapani. The complications are shown in Pl. II and Figs. 67, 71. The thrust mass above was called the Nihal thrust, after the village situated where the first thrust (I) obliquely crosses the Kuti river. The Nihal thrust was again found with similar complications on the Shiala glacier (Figs. 90—93) and on the north-east side of Lebong Pass (Pl. IV, Sect. 8; Pl. V Sect. 9a). Already there, the underlying formations begin to show thrusting movements, though connected with folding of no large amplitude. The first black band of Kuling shales thus appears on the Dhauli in a more interior zone, about 4 kilometers SW of the Nihal thrust. Nothing is yet known of the north-western prolongation.

The second thrust which we called after the Thumka Gad is the one already recognized by GRIESBACH in Tera Gad above Kalapani. It is a thrust-fold on the south side of Tinkar Lipu on the Nepal-Tibetan boundary (Fig. 74). Towards WNW the thrust line passes over Lilinthi

camping ground and Tera Gad. It was seen at a distance, crossing the wild mountain-crest north of Nihal and is wonderfully exposed on the Chaga Pass, east of Kuti. The Silurian quartzites are partly thrust directly over the Spiti shales, while in other places there are Triassic limestone sheets crushed between, which may be regarded as the relics of a reversed limb (Fig. 85—87).

Northwestward of Kuti this Thumka thrust is not only sharply defined, but the underlying Kioto limestones are piled above each other in narrow folds with Spiti shales in the squeezed synclinal zones (Fig. 95). These narrow Triassic folds are transformed to a normal upright shape in the uppermost Kuti Valley (Wilsha), where the Thumka thrust sheet overrides them independently. The thrust is seen thence up to the Darma Pass, where it covers a beautiful upright anticline of Kioto limestone (SW dipping fault of GRIESBACH). The distance along this thrust Nr. II, from Lipu Lek to Darma Pass, is 60 kilometers.

Nothing more is known up to the uppermost Gori Valley where the tectonics have already greatly changed. A peculiar thrust is indicated above Dung (Fig. 107), but this north-western region is more and more transformed to normal folding of a north-western pitch, while the axes trend towards NNW and nearly north. The thrusts have disappeared or are represented by the older sedimentary formations.

At the region of the Mangshang Pass, we found a third thrust of Silurian above Permo Triassic. The folds of red Silurian on the Tibetan side of the Zaskar range, which are overlying towards SW, are covered normally by the Triassic sequence and then thrust twice or three times more by the Lower Silurian (Pl. V).

All these zones seem to pass towards NW to normal folds, pitching below the Flysch and the Exotics (Fig. 110, 131, 132).

The Exotic Thrust Sheets of Tibetan Facies

The problem of the Kiogars on the north-western Tibetan border has been discussed, and VON KRAFFT's peculiar idea of volcanic explosions definitely rejected. But even the conception of thrusting from the far north-east leaves many problems unsolved. One point, more important than all local tectonical observations, was already fully realized by DIENER and VON KRAFFT, viz. the complete difference between the Tibetan facies and that of the Tethys Himalaya. But there is more than one Tibetan facies. Besides the Kiogars, where a normal succession of Kiogar limestone (Dachsteinkalk) to Jurassic oolite and Cretaceous (?) limestones and shales was found, there is the Chirchun facies, only known so far in the shape of isolated blocks upon and in the Flysch, together with the associated basic igneous rocks. This Chirchun facies is characterized by blocks of Crinoid limestone (Permian), ammonitic red limestones of Lower and Middle Triassic, unfossiliferous "Dachsteinkalk" and red and white Liassic limestone with radiolarian chert. Of this series of exotic blocks, only the Kiogar limestone, called "Dachsteinkalk" is of the same type in both series, though perhaps not present amongst the Chirchun blocks.

These differences of facies are not only cogent respecting an origin in the NE at a long distance, but we must conceive two distinct sub-types of facies of Tibetan origin, and of a very deep marine trough.

Thanks to GANSSER's audacious excursions into forbidden Hundes (Tibet), the conjectured continuation of the Flysch with exotic blocks and basic igneous has actually been demonstrated. Though covered over wide areas with terraced gravel and rather young basic sheets, the Flysch with the same exotic blocks was again found on the Shib Chu in a zone 25—30 kilometers north-east of the Kiogars, at Amlang-La, and at Jungbwa on the western shore of Raksas Lake, thus over a region of 100 kilometers from NW to SE. These occurrences apparently represent the prolongation of the Chirchun zone.

Of the Kiogar series no more trace was encountered farther in Tibet. As seen from

the top of the Kiogars, the Kiogar formations extend over 20 or more square kilometers north and east beyond the Tibetan boundary. Farther north they seem to dip below the gravel, while they open out to the sky on the South-East. The only plausible explanation that can be given with our present knowledge is that they were mainly weathered away in Hundes and then covered.

The Chilamkurkur-Raksas series covering a large zone north of Jungbwa, the only space for the origin of the Tibetan facies and the root of the exotic thrust sheets seems to be the zone between Raksas Lake and the Kailas, 60—80 kilometers behind the frontal region.

F. Kossmat (35, p. 288) considers the zone of Leh on the Indus with its trap to be the north-western continuation of the Kiogar Klippen. Although no exotic blocks are known to exist in that region, it is about the only one which may correspond to the Exotics of Hundes (see also the instructive section of R. Wyss, Die Alpen VII, Nr. 8, 1931, p. 290).

The Chilamkurkur-Raksas-Zone

Looking from Balchdhura towards north-east, low calcareous mountain ranges of a normal minor folding are recognized. They seem to be formed of Triassic limestone and to represent the continuation towards north of the Tethys Himalaya which reappears below the gravel platform or below the exotics. The flat anticline of schists on the Raksas Lake may be the main anticlinal core.

Another, still larger anticlinal core rises south of this lake in the shape of the crystalline Gurla Mandhata.

The Transhimalaya

South of the Kailas, Gansser again found the Flysch with its characteristic basic igneous rocks and limestone blocks, so that this zone of Darchen may be regarded as forming part of the root of the Exotics.

However it may be, the back part of this Flysch is thrust towards NE over the Kailas conglomerate. It is the counterthrust of the Himalayan Tethys against the frame of the old Angara continent. The conglomerate and sandstone of Kailas must be Tertiary, judged by their contents of radiolarian chert of the Flysch type in the sandstone, while the older granite forms its normal basis (Pl. V).

The Kailas, 6700 meters, not only is the holiest mountain for several hundred million Buddhists and Hindus, but is also geologically an unique feature. It seems to present the highest Tertiary conglomeratic series of our globe still in the position of deposition. The accumulation must have been made possible during subsidence at low levels, after which followed a vertical erection of 7000 meters at least.

Types and Size of Thrusting

Regarding the thrust zones of Kumaon, we may distinguish types of different size and depth. Coming from the South, we notice

1. Marginal thrusts, of the type of imbricated scales or tiles, their roots being partly squeezed or cut off by the main thrust plane. They occur in the zone from Simla to Kumaon, and may be compared to the frontal Helvetic and Ultrahelvetic thrust sheets of Switzerland (Wageten, Aubrig, Mt. Bifé, Voirons etc).

2. Secondary thrust sheets of the interior Lower Himalaya. Indications of such were found in the shape of gneiss at Chamoli, above Birehi valley and on Kuari pass. Their extensions and connections with the main thrust are still problematic. A definite result could only be obtained by detailed mapping.

3. The Main Central Thrust mass represents an enormous deep-rooted body of injected crystalline rocks, 10—20 km thick, covered with 10—15 kilometers of Algonkian, Paleozoic and Mesozoic sediments. It is apparently the same mass to which Mount Everest and Kangchenjunga belong The synclinal crystalline zones or outliers of the Lower Himalaya are apparently the prolongation towards SW of this Main Central Thrust mass, which have undergone secondary folding after the main horizontal displacement. The width of thrusting of the crystalline masses above the sedimentaries, visible on the surface, is 95 (Bhowali-Girgaon) to 110 kilometers (Garhwal) and thus of the same order as the great Thrust Fold of Darjeeling (Mt. Everest).

Including the frontal part which is weathered away and that of the root below the surface, the total horizontal movement must have been over 120 kilometers.

The thrusting having happened after the deposition of the Cretaceous flysch, the crystalline basal part of the Main Central Thrust mass must have been at a depth of 30 kilometers below the surface. There, within (not below) the Sial, at temperatures of 700° centigrade and more, the injection and migmatisation occurred, partly before and partly during the thrusting movement. Fine fluidal folding was observed in the Darjeeling region (Phot. 7, Pl. VIII) and to a lesser degree in the Central Himalaya of Kumaon.

The basis of the 30 kilometer thick crust, pushed from the North-East, slipped easily forward on the fluid substratum.

Obviously the sliding did not take place on the actual level of the Main thrust plane, but in the depth. A general uplift must have occurred after the horizontal sliding, followed by erosion. Ever since the crystalline thrust sheet has been dissected by erosion into separate synclinal zones or outliers, they can only have undergone passive displacements on the top of the lower thrusts and on the autochthonous basis. This is what we learn from the earthquakes and the dislocations of Quaternary deposits in the marginal zones.

4. Over the back part of the main root, the fossiliferous Paleozoic and Mesozoic sediments of the Tethys-Himalaya were piled upon each other. The thrusts are partly more of the fault type and partly recumbent folds with great complications of minor folding along the thrust lines, one type passing on to the other, as it is the case in the Alps. It is difficult to estimate the total amount of shortening compared with the original zone of sedimentation. It may be 30—50 kilometers in the middle part (Mangshang), but it diminishes towards NW, where normal folding is taking place. The slight changing of facies from one thrust sheet to the other also shows that the roots are not deep-seated.

5. The last great thrust from the Tibetan side is that of the exotic region of Tibetan facies. The root, according to GANSSER, must be supposed to be on the south side of the Transhimalaya where it is partly buried under the Sutlej-plain. If so, the thrusted width is 60—80 kilometers.

6. The Flysch zone on the south side of Transhimalaya which may be part of the exotic root, according to GANSSER, shows a counter-thrust towards north, though probably of a small amplitude.

A comparison of these different thrust sheets at once shows the capital difference of the deep-rooted Main Central Thrust mass (pli de fond) and the superficial exotic sheets. If it is difficult to our minds to comprehend the mechanics and the causes of such enormous horizontal movements of the first order, long distance movements of the shallow thrust sheets are still more puzzling. The row of exotic blocks, embedded in the Flysch and torn into isolated pieces, give the impression of a pull from the SW rather than of a push from the NE.

In the Alps the great thrust sheets are known to exist since the dawn of this century. All those who cried out "nonsense, impossible" had to capitulate before the facts which have been established since. Now we have got accustomed to deal with such thrusting, but we

must nontheless admit, if we are candid, that we do not understand the mechanics any better. Some of us, however, have learnt not again to cry out "impossible". There is no reason for rejecting the enormous thrusting of the Himalaya. There are plenty of other facts in nature that we cannot fathom. Evidently, the idea of sliding over an inclined surface (HAARMANN, AMPFERER) would be absurd for the Main thrust mass as well as for the Exotics[1].

Should our conclusions be looked upon as phantastic constructions, the words of ARGAND 1922 (1, p. 225) may be recalled:

«De tous les fronts partiels qui s'allongent du Pacifique à l'Europe, celui-là (Himalaya) est le plus doté d'énergie tangentielle: aussi les chaînes de la Téthys, bientôt asséchées, exaltent leur bombement axial, dans le Tibet et dans l'Himalaya, au-dessus de tout ce qui arrive ailleurs».

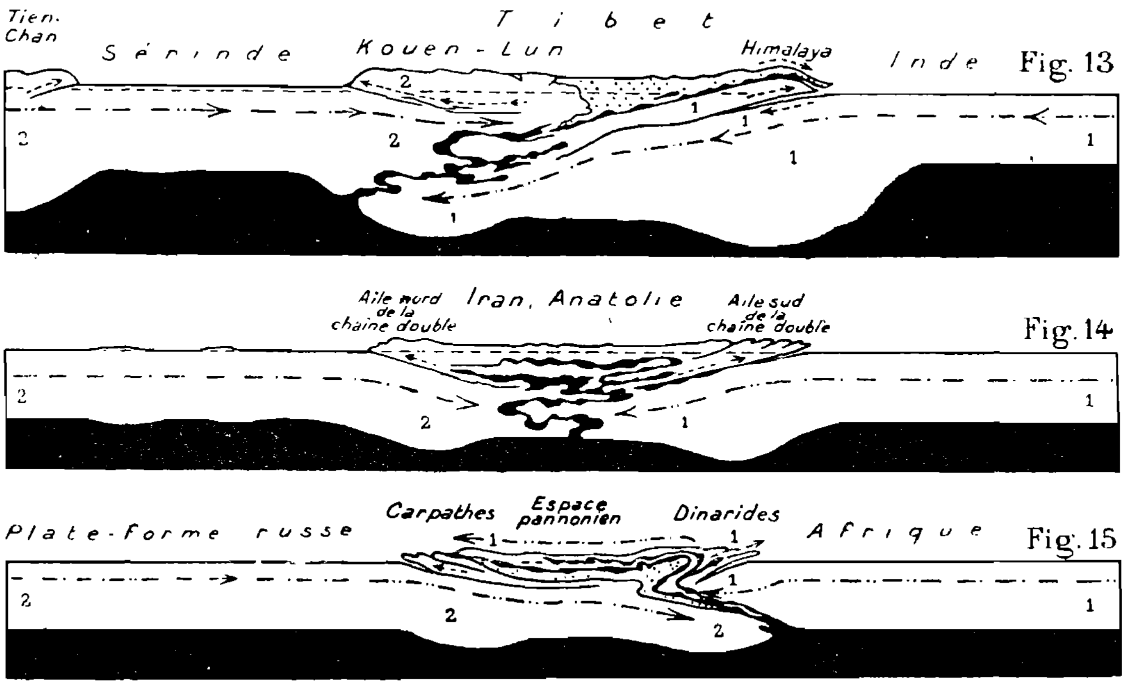


Fig. 158. Tectonical interpretation of the Himalaya by E. ARGAND, 1922.

Original Order of Facies and Contraction

If the above tectonical conceptions are accepted, we can now try to obtain a glimpse of the original order of facies, although our considerations will be hypothetical. This order, again beginning in the SW, is supposed to have been as follows (Fig. 159).

1. Crystalline and old sedimentaries of the Gondwana-Continent; Aravalli ranges buried under the Gangetic alluvial plain.
2. Autochthonous region of Simla slates and Eocene (Subathu), partly covered by Siwaliks. The original width may have been 100 kilometers.

[1] A possible explanation for the origine of superficial long distance thrusts is, to our way of thinking, the change in the velocity of the earth's rotation and of the position of the axes as related to the surface, both caused by cosmic impulses which must exist, since by gravitation alone the celestial bodies would tend to annihilate each other's rotation. See ARNOLD HEIM: Energy Sources of the Earth's Crustal Movements, XVI Intern. Geol. Congress, Washington 1933, pre-print June 1934.

3. Sedimentary zone of Lower Himalaya. Exterior zone, of which the normal succession is more or less established by the Anglo-Indian geologists: Mandhali-Nagthat-Blaini-Krol-Tal-Subathu. Original width 20 km or more.
4. Interior zone, characterized by a huge unfossiliferous series of limestones, dolomites, shales (schists) and quartzite, possibly corresponding to Krol-Tal (Tejam-Pipalkoti [1]). This series underlying the crystalline sheet is to be regarded as being thrust upon the autochthonous zone. The original width was 100 kilometers or more.
5. Nothing is left of the normal sedimentary cover of the crystalline Lower Himalaya zones within which a passage must have existed from the unfossiliferous Gondwana border to the fossiliferous Tethys-facies. The width is estimated at 120—150 km.
6. The Tethys zone of Himalayan facies, 110—130 km. Northern Himalaya Ranges of 20—60 km.
7. Zone of Chilamkurkur, considered as the normal northern extension of zone 6.
8. The supposed passage zone to the Tibetan facies (Exotics) is entirely unknown.
9. The Tibetan facies (Exotic blocks and Kiogar series) resulted from a very deep channel of unknown width.
10. The zone of passage to the totally different Transhimalaya is even more hypothetic.
11. The Transhimalaya representing the continental facies of the old Angara Continent opposite to Gondwana.

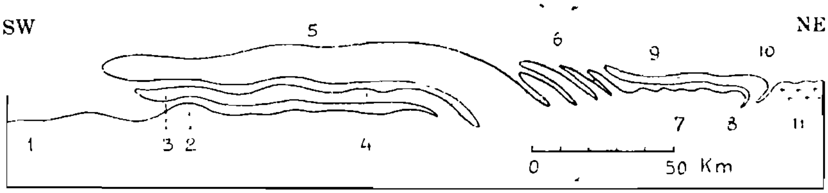


Fig. 159. Scheme of Supposed Order of Facies.

Finally we arrive at the most delicate question, which can only be solved after a complete geological survey of the whole Himalaya and Transhimalaya, viz. to that of the amount of contraction or reduction of the earth's circumference, involved in these Asiatic thrust-foldings. The Himalaya east of Nepal, with its more simple type of recumbent folding, raises fewer difficulties in connection with this study. We may estimate it at 150 kilometers, without counting the compression and possible thrusting of the Dalings over the buried autochthonous zone.

In Kumaon, we attain larger figures. The width of the Himalaya proper, from the border (Simla slates, Siwaliks) to the Exotics now being 170 kilometers on the average, was estimated above as at least $100 + 20 + 100 + 120 + 100 + 20 = 460$ kilometers as a minimum. The shortening of the earth's surface would thus be roughly 300 kilometers.

Comparisons with the Alps

The Alps seem to be that mountain range of our globe which, with regard to surface and structure, is most closely connected with the Himalaya. In some respects, there are striking resemblances, on the other hand characteristic differences.

First, of course, the Himalaya is a younger range. It is thrust from the higher north down over the subsiding Indian plain, while the Alps are thrust up towards north, their back part being the lower one. This, however, is only due to the greater age of the Alps, the main diastrophism having been followed by a subsiding of the hinterland and countermovement.

The border zones of the Siwaliks and Molasse, and their eroded contact to the thrusted

[1] If the border sedimentaries belong to the front of the Main Central Thrust and are not scratched off from the basal region, the order 3—4 is to be reversed.

older formations are strikingly similar (see p. 10). Already in 1867, MEDLICOTT compared the "fault" along the southern boundary of the Himalaya with the boundary of the calcareous Alps to the Molasse. But whereas the Alpine border zone (Voralpen) is formed of fossiliferous and nicely subdivided marine formations, the Lower Himalaya is unfossiliferous. This difference of facies excepted, the Krol thrust sheet or sheets recall the Helvetic thrust sheets.

The windows of Simla slate, with transgressive Nummulitic, correspond to the autochthonous Aar-massive with its crystalline schists unconformably overlain by transgressive Mesozoic and Nummulitic[1].

Nothing of the importance of the Main Central Thrust sheet is known in the Alps. In its place are the numerous Penninic thrust folds and the Austro-alpine Sheets like Silvretta, of lesser thickness, but reaching nearly the same amplitude. The huge thrust fold of Darjeeling comprises a unification of the Penninic recumbent folds. It is an 8 times exaggerated Antigorio fold or a duplicated and simplified Dent Blanche thrust fold. Take the frontal thrust sheets of the Krol Belt as Helvetic, the Garhwal windows as the Aar massive and the great crystalline thrustmass as Penninic, then the analogy is striking. In both ranges also the piedmont deposits from the primordial ranges (Siwalik-Molasse) have been erected before being reached by the thrust sheets which later locally overwhelmed the barrier and advanced towards the plain through the erosive gaps. Here, also the analogies of the crystalline rocks mentioned in the petrologic chapters with those of the Penninic Alps are recalled.

The Tethys Himalaya of Kumaon has some striking facies resemblances to the Austro-alpine Thrust-Sheets (Paleozoic, Triassic), but tectonically it is only formed of minor thrustfolds.

In a former chapter we already pointed out the similarity of the exotic regions to those of the Alps, especially of the Kiogars to the Klippen of Central Switzerland. But they emerge far behind the main deep-rooted thrust zone, while the roots of the Klippen- and Simmendecke of the Alps are supposed to be situated immediately behind the Penninic ones[2]. Many of the still unsettled questions regarding the exotic blocks are similar in both countries, although the stratigraphic phenomenon of acid crystalline rocks in Wildflysch does not occur in the Tibetan zone. Regarding the Tibetan facies, its analogies in character and age to the Austro-alpine Region (Hallstatt, Adneth) already puzzled the first investigators (DIENER, VON KRAFFT).

Another analogy of the counterthrust towards the Transhimalaya (and that of Kuen Lun) is found in the Alps, where behind the Penninic and Austride roots follow the Dinaric counterthrusts. The difference remains that the Asiatic hinterland of the Himalaya has not yet been subsided like the Mediterranean hinterland of the Alps.

As to the shortening, the figures we obtained are not far off from those of ALBERT HEIM[3] of 200—300 kilometers as given for the Alps. The greater thickness of the formations and the magnitude of the main root of the Himalaya is contrasted with the greater number of thrust sheets and their enormous complication in the Alps.

According to the conception of ARGAND and STAUB[4], the Himalayan thrust and upheavel are the result of a contest between the old continents of Laurasia (Angara) and Gondwana. The battle was won by Angara which overwhelmed the deeper-seated Gondwana. The original boundary between the two is marked by the Main Central Thrust, above which must have been the passage of facies of the unfossiliferous, though already geosynclinal border region of Gondwana to the Tethys.

[1] The Nanga Parbat, 8100 meters, might be called the Himalayan Mont Blanc, but it seems to be behind the main crystalline roots.

[2] or in GIGNOUX's opinion even north of them.

[3] ALBERT HEIM, Geologie der Schweiz, Bd. II 1919, p. 50-51.

[4] R. STAUB, Der Bewegungsmechanismus der Erde (1928), considers the countermovement of Gondwana and Laurasia (Angara) at 3800—5000 kilometers!

Morphology and Glaciation

1. Morphological Features of the Himalaya in Kumaon

The first impression received when coming from the Indian plain is the sudden rise of the Siwaliks and their facing towards the plain. This is caused by the general young movement towards south and a normal dip of the sandstones towards the Himalaya. The Main Boundary Thrust is usually not defined morphologically, the forested front ranges of the Siwaliks passing on to those of the Lower Himalaya. The same is the case between the border ranges of limestone and the crystalline regions. Only the geologist distinguishes the limestone mountains at a distance from those of other formations.

The traveller first reaching the Himalaya, either at Darjeeling or Kumaon, is surprised at the vast extension of the wooded ranges in the Lower Himalaya. Apart from the frontal region, the elevation of the undulated country does not increase. Even the contrary is the case. From the famous top of Tiger Hill at Darjeeling, the view towards north gives even the impression of a general depression before the great rise to the snow mountains of Kangchenjunga begins. The same is the case in Kumaon. Behind the rounded tops of the mountains of Naini Tal and its surroundings, which reach 2500—2600 meters, follows a region of undulated ridges of lesser elevation before they increase again to nearly 3000 meters (see panoramic view of A. Gansser in 30, 1937). The elevations are more or less independent of the structure. While the crystalline syncline of the Almora zone corresponds in general to the surface depression, the contrary is the case with the crystalline synclinal Dudatoli outlier. Thus, considered as a whole, the appearance of the Lower Himalaya is that of a peneplain with ridges of 2500—3000 meters, dissected by deep erosive valleys (Phot. 5, Pl. VII).

When coming to the Central Crystalline Zone, the elevations rapidly increase, the slopes become steep and climb above the forested zone which reaches 3700—4000 meters. The transversal rivers have formed tremendous gorges with their characteristic convex slopes which demonstrate the accentuation of erosive power, caused by recent uplift (Phot. 13, Pl. IX; Phot. 22, Pl. XII and Text Fig. 31, 56). The Kali has cut its bed 4300 meters below the adjacent Nampa and even the widened, nearly longitudinal valley of the Gori Ganga below Milam is 4400 meters below Nanda Devi. This, in truth, is little compared with the "prohibited" gorge of the Arun in Nepal which is cut 5000—6000 meters below the top of Mount Everest.

The water current and erosive power is enormous. The Gori Gorge below Rilkot is an almost continuous cataract. A similar gorge is that of the Alaknanda below Badrinath.

The flat ice top of Nampa excepted, most mountains of the Central Himalaya form sharp peaks and crests. An enormous wall of over 3000 meters height is that on the east side of the smaller Nanda Devi peak. In the Badrinath group, the Satopanth and its western neighbour, Sonero Parbat, both granite peaks of 7000 meters, are the boldest summits.

The altitude of the prominent mountains of the Central Himalaya is not much dependent on the rock of which they are formed. Thus, Nampa is formed of the transitional zone from the crystalline series with dykes to the phyllite. The head of the Godess Nanda, 7820 meters, is a syncline of phyllite with quartzite, while the Badrinath group is dominted by intrusive granite.

Dyhrenfurth explained the exceptional elevation of Chomo Lungma (Mt. Everest) as caused by locally increased uplift (Hebungsinseln). We see no reasons for this view. Certainly Nanda Devi has nothing to do with an increased local uplift. If on the other hand the structure and quality of rock were of decisive importance, this synclinal peak of phyllite would not exist. It seems more likely that the position between the river systems of the Kali and the Ganges exempted this region from farther destruction.

A kind of "Gipfelflur" thus resulted in the Himalaya, as well as in the Alps, independently of the geological foundations (Albert Heim, A. Penck). In the Himalaya it is controlled by the

general erosive basis of the Indian plain. If the highest mountains: Kangchenjunga, Everest and Dhaulagiri are opposite the greatest fore-deep of the Gangetic plain, this may be the expression of a balance movement: The highest mountains are in regions of greatest diminution of weight caused by the greatest erosion, similar to an ice-berg which, breaking up into pieces, forms peaks of increasing height before being completely destroyed.

The morphological appearance of the Siwalik border, approached from the plain, is repeated on a giant scale by the view of the great Central Range. Indeed, already at a distance of 100 kilometers the inclination of the crystalline rocks and quartz-phyllite towards NE is recognized. It caused the great precipices facing the fore land (Phot. Pl. I). It is a similar appearance to that of the Alps seen from the North.

In the Tethys Himalaya the morphology is distinctly connected with the stratigraphy and tectonics, on account of the great differences in resistance of the Paleozoic quartzite and the soft Mesozoic shales. The highest peaks of 6000–7000 meters are usually formed of north-easterly dipping Muth quartzite, while the general north-eastern inclination of the strata caused the steeper slopes facing the Indian plain.

The usual relief-maps with their stupid conventional light from NW that does not exist in nature gives a wrong impression of the morphological features, in the Himalaya as well as in the Alps and of all other mountainous countries of the northern hemisphere, the region beyond the polar circle excepted. This is the reason for having worked out a map with natural evening light from the South-West, which has been added to our book recording the expedition (30).

The boundary range and watershed to Tibet are called the Zaskar range on the official maps, though locally this name is not known. Its highest summit was found to be the Shangtang 6480 meters above Kuti, probably composed of Muth quartzite. Though made of different stratigraphical horizons, from the Silurian to the Triassic, and having different tectonical positions, the peaks from Lipu Lek to Balchdhura, over 100 kilometers, are all 6000 ± 400 meters, and the passes 5100—5600 meters.

Morphological Features and Drainage of the Tibetan Highland

The aspect of the Zaskar range from a distance, and the observations of Gansser permit to give a short summary of the morphological properties of this Highland belonging to the Tibetan Province of Hundes. The main features are the plain of the great lakes Manasarovar and Raksas, at 4550 meters, and their former outlet of the Sutlej. It is formed for the most part of Pleistocene gravel and young basic igneous rocks. The relatively low Chilamkurkur ranges even included, it is a plateau-like country, greatly contrasting with the Himalaya. The snow-clad mountain ranges of the Transhimalaya, with the outstanding Kailas (God Shiva's lingam) in front of them only follow beyond this depression.

Out of this great plateau rises, towards east, Gurla Mandhata, the crystalline dome-shaped anticline, which may correspond to the crystalline mountain of Shipki 22210′ (= 6750 meters) on the north side of the Sutlej, 280 kilometers farther NW.

The region around the Gurla massive is one of the most peculiar and most interesting of the whole Himalaya, with regard to the drainage. On the south-east side of Lake Manasarovar is the flat pass which forms the watershed between the Brahmaputra (= Tsangpo) and the Sutlej. The recent stoppage of the outlet from the great lakes to the Sutlej, already observed by Sven Hedin, is explained by Gansser as having a tectonical cause which permitted a sub-surface outlet towards south into the great Kosi of Nepal. The water of lake Manasarovar (4500 meters) flows into lake Raksas. The connecting channel however is frequently dry, and the Raksas lake (4530 meters) has no superficial outlet. A vast muddy plain extends in the

region of the former northern issue of Raksas lake designed as the "old bed of the Sutlej" on the Indian map Nr. 62 F. The meandering waters now flow towards the lake. The rivers east and west of the Kailas change their course a few kilometers after reaching the plain. Instead of flowing towards SW and W to the Sutlej, they are branching and flow into the Raksas lake. These facts are explained by a recent subsidence (GANSSER). The valley was of a flat basin shape and did not follow the border of the Transhimalaya as shown by the subsequent gravel terraces of the Sutlej which rather point to repeated erection in that western region.

The Kosi and the Sutlej are the only two rivers which drain the Manasarovar plain by channels crossing the Himalaya ranges. All other rivers of Kumaon are tributaries to the Ganges and the Kali and have their sources in the Zaskar range, thus carrying exclusively Kumaon- and some north-western Nepalese Himalayan water.

Mountain Slides and Lakes

DYHRENFURTH (15) already drew attention to the great difference between the Alps and the Himalaya with regard to the occurrence of lakes, and explained it with ALBERT HEIM's interpretation that the beautiful border lakes of the Alps are due to a general subsidence, whereas a similar tectonical movement did not occur in the Himalaya. The Himalaya is in a younger stage of mountain forming, within which the range is still rising. In a later periode, after the cessation of the crustal pressure, a similar subsidence may cause the marginal valleys to be drowned to fjord-like lakes.

In the regions of Kumaon and NW Nepal, we found only a few small lakes which are either dammed by moraines (Joling Kong, Phot. 31, Pl. XIV) or by mountain slides (Gona Lake). In addition, the official topographic sheets 1" = 4 miles show numerous lakes in the upper Kuti valley and a large fjord-like one at Chirchun, on the Tibetan side. They are gravel flats only, but may once have been glacial lakes.

The origin of the small lakes in the border region of Naini Tal was already the subject of a lively discussion in the last century and is still pending. All these lakes are so small that they do not appear on our map 1:650.000. The absence of larger ones is striking.

Regarding the mountain slides, it was not surprising to find them in great number in such a high region of young dislocation. But they are usually small compared with the prehistoric mountain slides of the Alps[1]. The reason for this may partly be due to the strong erosion which washed away many old slides, and partly to the small extent of the last glaciation and the correspondingly slight glacial protection, after which, in the Alps, numerous large interglacial rock falls occurred, including the largest, of Flims, with a content of 12 cubic kilometers, covering 40 square kilometers. In the Himalaya there was no such long preparation followed by an uniform collapse of large walls, but a more gradual break-down in smaller quantities.

The largest and probably pre-Würm slide we encountered seems to be that one on the Kuari Pass, of 8- 10 kilometers length and a volume of about 2 cubic kilometers.

The youngest, steepest and finest is the rock fall of Gona which occurred in September 1893 and formed a lake of 3.5 kilometers in length. We refer to the local descriptions after each chapter, and to Phot. 216 in 30.

Recent Glaciation

As time was pressing, we could only study en route the actual glaciers. Some indications of the types and shapes with measurement of the elevation of the tongue are found in the descriptive text. The largest glaciers of NW Nepal and Kumaon encountered on our traverses are

[1] ALBERT HEIM, Bergsturz und Menschenleben, Vierteljahrsschr. d. Naturf. Ges., Zürich, 77, 1932.

a) The Shunkalpa as the joint end of Kala Baland and Thercher glaciers.
b) The Milam glacier of 19 km length, being the one that reaches the lowest level: 3500 meters,
c) The Bhagat Karak (above Badrinath), also of about 19 km. Larger than all these is the Gangotri NW of the Badrinath (26 km).

The snow line, in 1936, was found approximately at the following elevations:

Bhagat Kharak, 5300, Balchdhura on the Tibetan front 5500—5600, Kungribingri 5650[1], Gurla Mandhata and Kailas 5800—6000. The rising towards Tibet is natural because of lesser snow fall and a more continental climate. Accordingly, no glaciers can exist where the mountains are below 5500 meters, though firn fields may occur on the northern slopes, down to about 5100 meters (Lipu Lek).

Regarding the formation of hoar ice found above 6000 meters, and of the different types of ice- and firn furrows, we refer to p. 77.

Special attention was paid to the thrusting of one glacier over another, a phenomenon which was described in a striking way by PH. C. VISSER from the Karakorum[2]. Similar cases were observed by GANSSER at the junctions of the Nampa glaciers (Fig. 46, 49). On Bhagat Kharak and Satopanth, glacier thrusting also seems to exist, but the ice being covered with blocks, no clear distinction was possible.

Folding by lateral compression was found on the Shunkalpa (Phot. 36, Pl. XV).

The glaciers of the main valleys on the Indian side differ considerably from those of the Tibetan side. The Tibetan glaciers are relatively clean and form smooth streams with little cracks (Mangshang, Chirchun), while those south of the Tibetan watershed are widely covered with blocks. Thus, on the glaciers of Milam, Satopanth and Bhagat Kharak, the lower part looks like a mud-stream. The same thing was observed on the Zemu glacier, at the east side of Kangchendjunga by the BAUER-expedition. The ice is only seen in local crevasses and hollows, as far as 5—10 kilometers apart from the snout.

Only on the Kala Baland were seen remparts of a middle moraine.

The question thus arises wherefrom the enormous amount of upper moraine blocks may derive. Obviously they cannot come from the walls on the side of the glacier where they are dammed by the subrecent lateral moraine. The only possibility of origin, thus, is the border of the collecting snow fields (Firnrand), where they become covered by the annual snow fall and disappear at the depth, until they re-appear in the region of progressive ablation. We recall the observation of the Nampa glaciers by A. GANSSER (p. 65).

This result corresponds with the valuable observations of STREIFF-BECKER[3] made in the Alps of eastern Switzerland, according to whom glacial excavation is confined to the uppermost part of the glacier (Firnmulde).

In numerous places the ice tongue was observed thrusting over the thick ground moraine (Milam, Lebong, Satopanth), being incapable of removing the super-abundance of blocks and mud. The lazy stream not only has no more power to scratch the rock-ground, but accumulates, similarly to a muddy stream which fills up its beed. This glacial protection of the pre- or interglacial erosive rock-forms is the greatest contrast to the furious erosive power of the running water. The contrast illustrates the young age of these high mountains. Only in lower countries of lesser water power the ice, with its enclosed stones, touches the rock-ground and is capable of glacial erosion.

In accordance with these observations are the rare cases of glacial striation on the rock, on the side and below the glaciers. Such were described as exceptions from the Shiala glacier and of the Alaknanda, the first of subrecent, the second of Pleistocene age.

[1] These figures correspond to those of DIENER (11): Uhadhura Pass 5400—5500 m. On the SW side of the High Ranges which are more attacked by the monsoon, the snow line descends to below 5000 meters.

[2] TH. C. VISSER, Gletscherbeobachtungen im Karakorum. Zeitschr. für Gletscherkunde, Bd. XXII, 1935.

[3] R. STREIFF-BECKER, in: Zeitschr. für Gletscherkunde 1938 (in the press).

The incapacity of glacial erosion, at present and in the past, is also illustrated by the lateral moraines. Along all the larger glaciers we found sharp crests, 15 to over 50 meters above the present ice and still higher above the lateral valleys, between this moraine crest and the rock wall. This illustrates with unparallel lucidity the incapacity of the glacier during that former and more powerful stage in lateral expansion. The glacier even then did not touch the side walls of the valley, but was riding on the top of a rampart of ground moraine. The amount of blocks is so large that the glacier looks as if it were suffocating!

These glaciers are a disappointment to the tourist who thinks of the magnificence of blue ice streams as such are found in the polar regions. He has to climb high up to the steep tributaries to get any satisfaction in glacial scenery.

The above ideas are in complete accordance with those expressed by GARWOOD in 1903 (17, p. 298[1]) and by DYHRENFURTH in 1930 (15, Phot. No 14). The Yamatri glacier of the Nepalese side of Kangchenjunga is perhaps the most striking example ever figured of a glacier which flows high upon a dam of moraine. The lateral channels, exactly of the type of those of Bhagat Kharak and Satopanth, are relatively so low that it takes an hour to climb 300 m high over the lateral moraine to reach the ice-stream. Imagine a railway dam with the rails on the edge, and the muddy ice between, and one has the Himalayan type of a main glacier in its lower part.

In the Alps, the Macugnaga glacier on the great eastern slope of Monte Rosa is of a similar type. It is also in a region of a deep erosive basis, showing an increased contrast of water erosion and glacial protection.

Regarding the age of the sharp subrecent lateral moraine which is a constant feature of all main glaciers, not only of Kumaon but also of Sikkim, the information given in 9, 1907 for the Milam glacier is of primary importance. If the old native was correct, then this subrecent stage was that of about 100 years ago which corresponds to the period of great extension of the glaciers in the Alps.

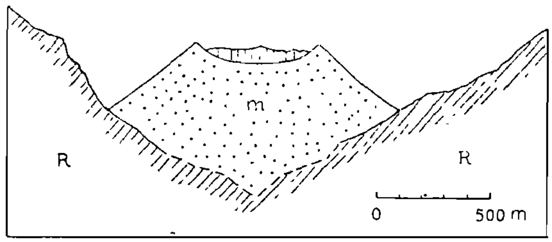


Fig. 160. Transverse Section of Yamatri Glacier after Photograph by G. DYHRENFURTH.
m = moraine r = crystalline rock.

Pleistocene Glaciation

Older Glaciations

The problem of pleistocene glaciation in the Himalaya is as yet unsolved. Much research work has been done since about 1870 in the NW (Kashmir to Karakorum). Four periods of pleistocene glaciation have been distinguished corresponding to those of the Alps (DE TERRA, 63, 1937). THEOBALD (64, 1880) found and described large erratic blocks on the Jhelum and the lower Indus which are scattered down to the alluvial plain, a few hundred meters only above sea level. The same author (65) described the lakes of Kumaon, such as Naini Tal, as being of glacial origin, dammed by moraines which have partly disappeared.

If these occurrences may be questioned, moraines exist in the Kashmir valley above and below the Karewa lake deposits, at altitudes of 1500 meters (WADIA, SAHNI, DE TERRA). OESTREICH found moraines down to 1200 meters. NORIN, in a very careful study on the Chenal river (48, 1926) in the Punjab has determined the end of the glaciers at 950 meters (Kishtwar stage) and that of the recession stage (Shigar) at 1350. The whole region was found to have undergone recent

[1] "These glaciers, by protecting the valleys they occupied from river erosion, would thus prevent the ajustment which we should otherwise expect to have taken place. That this protection by glaciers is a very potent factor is further illustrated by the raised floor preserved under the glacier, at the head of the Rathony valley itself, not to invoke numberless instances from other glaciated districts of the world." (GARWOOD)

uplift, partly along faults or flexures, of 225—400 meters and above. "These epeirogenic movements lowered the base-level of the river system and increased the gradient of the river courses. Thus, the erosive power of the streams was highly augmented and the dissection of the ancient valley-bottom went on rapidly."

On our excursions we encountered in some places deposits resembling ground moraine (Gori Ganga, at about 1500 meters) but we looked in vain for scratched pebbles. Only above 2000 meters indisputable moraines were found. This recalls the writer's result on Minya Gongkar in Chinese Tibet[1]. We may explain this discrepancy by admitting that the morphological features and moraines have disappeared by continous erosion. Or is the difference with Kashmir partly explained by tectonical movements since the first glacial periods, the Central Himalaya rising and the plain of the Indus subsiding? V. WISSMANN (71, 1937) decidedly pleads for the first explanation regarding southern and eastern Asia in general.

Moraines

Following the great transversal rivers upwards, we encountered the first indisputable moraines:

1. On the Kali at Malpa, 2150 meters above sea level
2. On the Gori Ganga at about 2200 meters
3. On the Alaknanda at 2030 meters.

On the Kali, we really seem to be at the former glacier tongue. On the Gori, the former end is uncertain, the moraines being indistinct or washed away. But on the Alaknanda, the lateral moraine walls are nicely preserved, so that the former end of the glacier—of the Würm period probably must really have been at about 2000 meters. The glacier then had a length of 55 kilometers, apart from the Tibetan watershed. The main valleys, Kali and Alaknanda-Saraswati, carry no more glaciers, and the snouts of their tributaries are at 3700–4000 meters and higher. The difference is considerable, though nothing alike to that of Europe and North America. VON WISSMANN considers that when going east over Eurasia, the difference between the older Pleistocene stages of glaciation to the last one (Würm) is increasing, so that the connections seem to be missing. This must be the case on the Yangtse, where J. S. LEE's surprising results of glaciation down to the alluvial plain seem to be confirmed also by other investigators' latest observations.

Above the 2000 meters level, several stages of recession have been found, almost in every glaciated valley (Fig. 46).

On the Kali, the first rampart of recession is that below Budhi, with its top at nearly 2700 meters (Budhi stage). It may correspond to that of the Alaknanda at Kalian Koti 2550 meters.

The next barrier is that of Garbyang, at about 3250 meters, but the real moraine seems to reach not much above 3100 meters (Garbyang stage). It may correspond to Badrinath on the same level.

In the Api-, Nampa- and Tinkar valleys (Nepal) the next stages are well preserved and of 300—400 meters thickness from their lower end to their shoulder. We thus consider only the upper edges. They are:

The Api stage at 3700 meters, corresponding to that of the Nampa valley at 3600 meters, and probably to those of Tinkar at 3750 meters.

Whereas the next stage in the Api valley, at about 4050 meters, is already near the actual ice tongue (4150 meters) and may be subrecent, there are further receding stages in the Nampa- and Tinkar valleys, at 4000—4150 meters (Tharadhunga stage), 3 kilometers SW of Tinkar Lipu, at 4600 meters (Tinkar Lipu stage). This last rampart yet may be older than the subrecent stage of 100 years ago.

[1] ARNOLD HEIM, The Glaciation and Solifluction of Minya Gongkar. Geogr. Journal, Vol. 87, May 1936.

Yet the great moraine at about 4300 meters of the Lilinthi valley, at the junction with the uppermost Kali, has to be recalled, behind which extends the flat bottom of 4250 meters, probably a lake filling (Phot. 20, Pl. XI).

Pleistocene Lake Deposits

The occurrence of sandy loam and varves, between or above moraine in 4 different places, is a striking fact. They are:

1. Kali above Malpa
2. Lake of Garbyang.
3. Lake deposit of Nampa valley
4. Lake deposit of the Alaknanda.

Referring to the local descriptions, the results only need to be discussed.

The lake of Garbyang, of 10—11 kilometers length, is by far the most important, also on account of its filling of 200 meters or more of sandy loam, with gravel layers and varves. Moraine with scratched pebbles is found on the slope and at the bottom.

Even clearer than here is the occurrence of moraine above the lake-loam in the Nampa valley and on the Alaknanda. The only question that remains is wether these lakes were interglacial or inter-Würm. On the Alaknanda, it seems to be the upper moraine which continues to the former glacier end at 2000 meters. On the Kali, the lake deposit must be older than the Budhi stage whence the gravels have been washed down which cover the varves. Although they may not represent the same interval, all four lakes are of later pleistocene age, and recall the famous Karewas of the Kashmir valley. While the latter have been strongly folded and raised, no similar fact was observed on the Garbyang lake deposit where the upheaval must have been more uniform.

Post Scriptum

Auden's Tectonical Results

The fore-going manuscript was written, when in February 1938 the author received the new paper by J. B. Auden: The Structure of the Himalaya in Garhwal, in Records of the Geological Survey of India, Vol. 71, accompanied by 3 Plates of tectonical sketch-maps and sections.

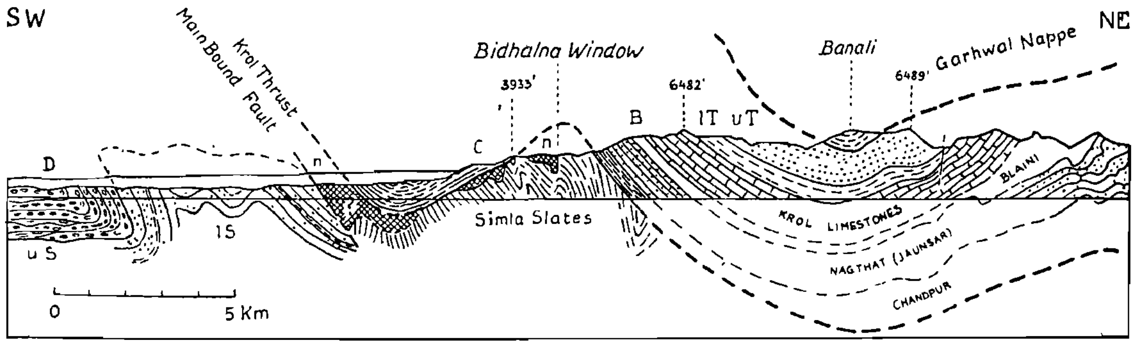


Fig. 161. Section across the Bidhalna window and the Banali outlier in Tehri State after J. B. Auden 1937.

Autochthon: S = Simla slate (Pre-Cambrian?); n = Nummulitic, calcareous shale and quartzite; erosive surface on the Simla slates; lS = lower Siwalik; uS = upper Siwalik; D = Dun gravel.

Krol-Nappe, normal series: C = Chandpur (green and purple slates); N = Nagthat (variegated quartzite); B = Blaini; K = Krol; lT = lower Tal (micaceous slates) passing to uT = upper Tal (quartzite).

Garhwal-Nappe (Amri-N.): Chandpur (sericite schists).

The paper has been expected for some time, and the reading of it was exciting, in as much as it completely confirms our "impossible" thrusting conceptions of immense size and extension. AUDEN with his wide field-knowledge of Sikkim, Nepal, Garhwal, Tehri-Simla and Kashmir-Karakorum has made a great advance towards the tectonic understanding of the Himalaya. His studies of Garhwal are of special value for a comparison, as they join our region towards NW. In the Ganges region, AUDEN distinguishes the following tectonical elements from below:

1. The Autochthonous, Siwaliks and anticlinal windows of Simla-slates (Pre-Cambrian) with transgressive Nummulitic.
2. Krol-Nappe[1], of a complete and normal series from Chandpur to Upper Tal, of 4—5 kilometers thickness.
3. Garhwal-Nappe (or Nappes), to which are counted the synclinal outliers of Satengal and Banali (Chandpur), NW of the Ganges. The two subdivisions are, from below:
   a) The Bijni-Nappe (Satengal, lower part NW, and Bijni SE).
   b) The Amri-Nappe (Satengal upper part, and Banali; Amri SE).

In the "preliminary attempt" section 3, Pl. 37, the non-subdivided Garhwal-Nappe is—apparently with some hesitation—connected with the thrust of the central crystalline range of Kedarnath-Gangotri: "It would seem possible, that the main Garhwal-Nappe joins up with the rocks at the base of the Main Himalayan Range and that the minimum distance of translation

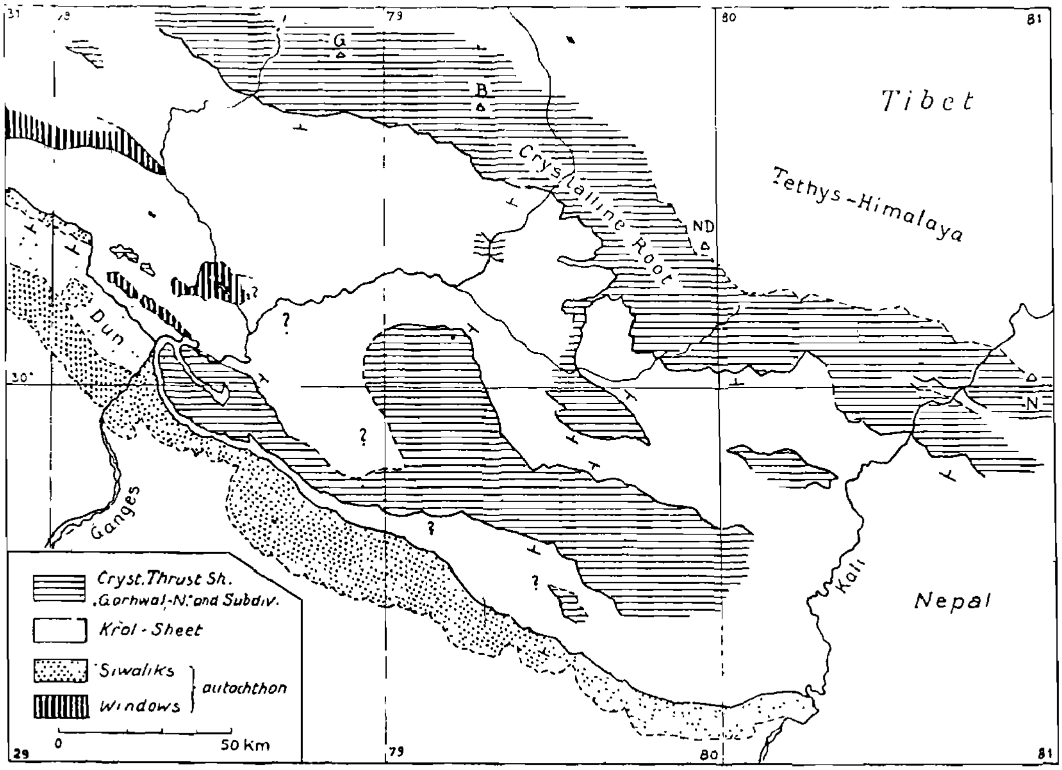


Fig. 162. Tectonical Sketch-Map of the Central Himalaya after AUDEN and the present authors, a preliminary attempt.

[1] The French word "nappe" means exactly the same as sheet and seems to be as unnecessary as the German "Fenster" for window.

of this tectonic unit may be about 50 miles (80 kilometers)." The sedimentaries underlying the crystalline thrust of the Central Range are indicated as ? Krol-Nappe.

On the Alaknanda, visited by both parties, we meet on delicate ground, though principally in complete agreement. It may be added that beyond the Dudatoli outlier we traced the "Baijnath-outlier" which leaves little space for a crystalline bridge from the Amri-Nappe to the root of the Main Central Thrust mass, which we regard as the root of the great "Garhwal Nappe" with its tectonical subdivisions. In the region of the Sutlej or north of it west of Rampur, a complete bridge to the great crystalline region may still exist.

According to the enormous thickness of the main root (crystalline + normal sedimentary series) of 30 kilometers or more, a great extension of the thrust mass as a whole is a priori probable. There are more than 300 kilometers from the Kali to the Sutlej, where the root may be followed, and whence it is supposed to continue yet far beyond. Possibly, even Mt. Everest and Kangchendjunga, 800 kilometers east of the Kali, are the continuation of the same Main Central Thrust mass which forms the root of the "Garhwal-Nappe".

The section Fig. 161 and the sketch-map Fig. 162 show the joint result of J. B. AUDEN and our tectonical conceptions.

LIST OF TEXT FIGURES

The Central High Range

The Northern Ranges (Tethys Himalaya)

The Exotic Kiogar Region

From the Himalaya to the Transhimalaya (Tibet)

Review and Conclusions

Sections Pl. I—V

LIST OF PHOTOGRAPHS

a) Photo-Views

b) Micro-Photographs

SIGNATURES OF THE SECTIONS PL. II—V

1. Lower and High Himalaya, unfossiliferous (in alphabetic order):

a	amphibolite, diabase and chloritic schists derived from basic sills
b	"Bergsturz", land slip
c	carbonates, mainly limestone, incl. marble
cs	carbonate with slates
cg	graphitoid layers
co	conglomerate
d	dolomite and dolomitic limestone
g	ortho (augen-) gneiss, injection gneiss
gr	granite
ls	lime-silicate (calcsilicate)
m	moraine
mg	mica schist with garnet
ms	mica schist (biotite and muscovite)
p	pegmatite and aplite dykes
pg	psammite gneiss, paragneiss
ph	phyllite
q	quartzite
qp	quartz porphyry, partly gneissic
qs	quartzite with schist, sericite-quartzite
s	sandstone
sh	shale; v variegated shale
sl	slate
ss	sericite schist, partly chloritic
t	talus, scree
tg	terrace gravel

2. Tethys Himalaya (in chronologic order):

Ma	Martoli series
G	Garbyang series
R	Ralam series
O	Ordovician (Shiala series)
Cr	red and variegated Crinoid shales (Low. Silurian)
M	Muth quartzite (with dolomite)
P	Permian, Productus (= Kuling-) shale and Eotrias (black)
Ch	Chocolate series, Low. Trias
K	Kalapani limestone, Middle Trias
Ks	Kuti shales, Noric
Ki	Kioto limestone, Rhaetic
L	Laptal series, Lias
S	Spiti shales, Portl.
J	Jurassic
C	Cretaceous
F	Flysch, Cret.
E	Eocene

3. Tibetan region (in addition to 1 and 2):

ex	exotic blocks
i	igneous, mainly porphyritic
id	igneous, dioritic
pt	peridotite and serpentine

CENTRAL HIMALAYA

Geological Observations of the Swiss Expedition 1936

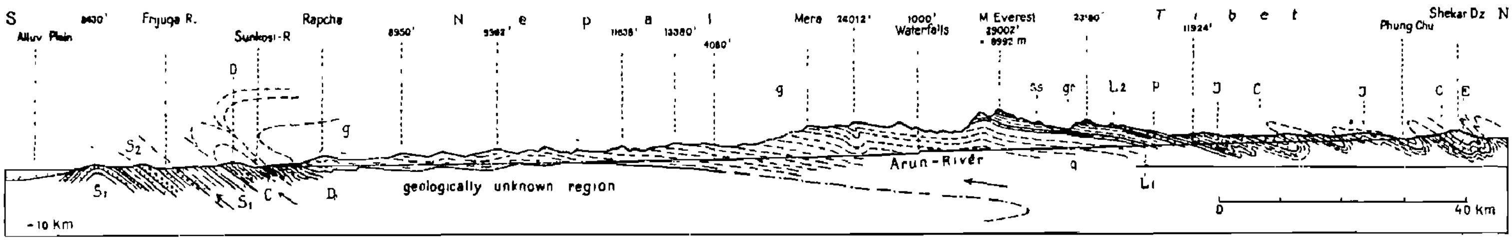
by ARNOLD HEIM and AUGUST GANSSER

ATLAS

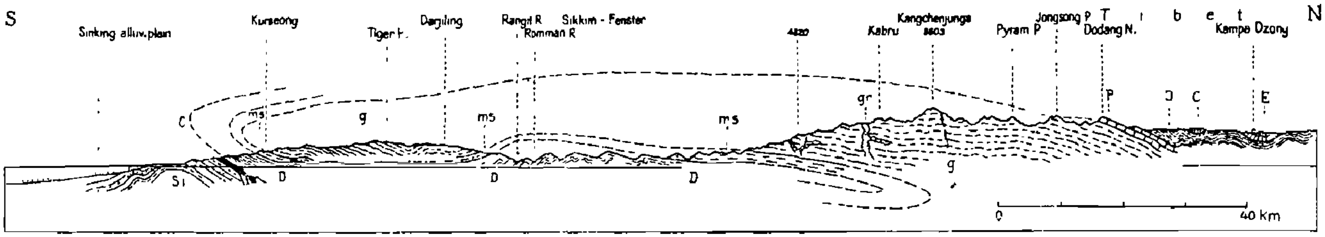
containing coloured plate with geological maps and a generalized section,

5 plates of detailed sections, 18 plates with

65 photo-views and 3 plates with 21 micro-photographs



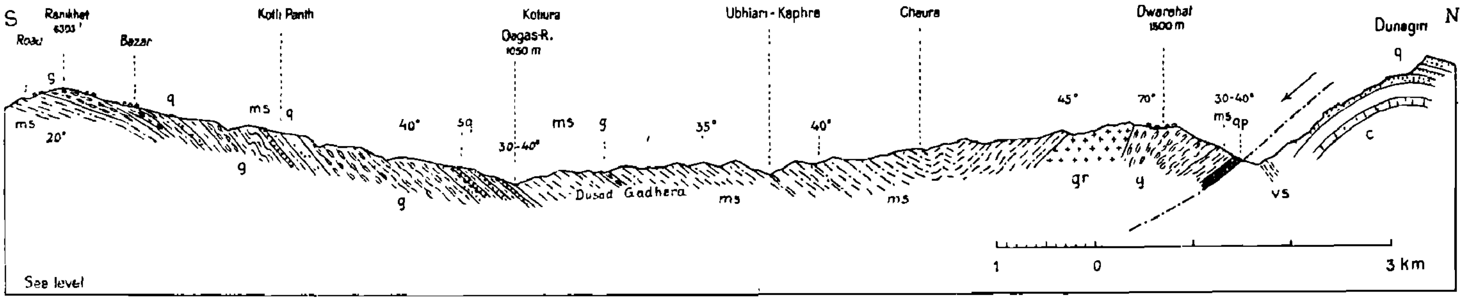
Sect. 1



Sect. 2

1 and 2 Tentative tectonic sections of Darjeeling-Kangchenjunga and Nepal-Mount Everest

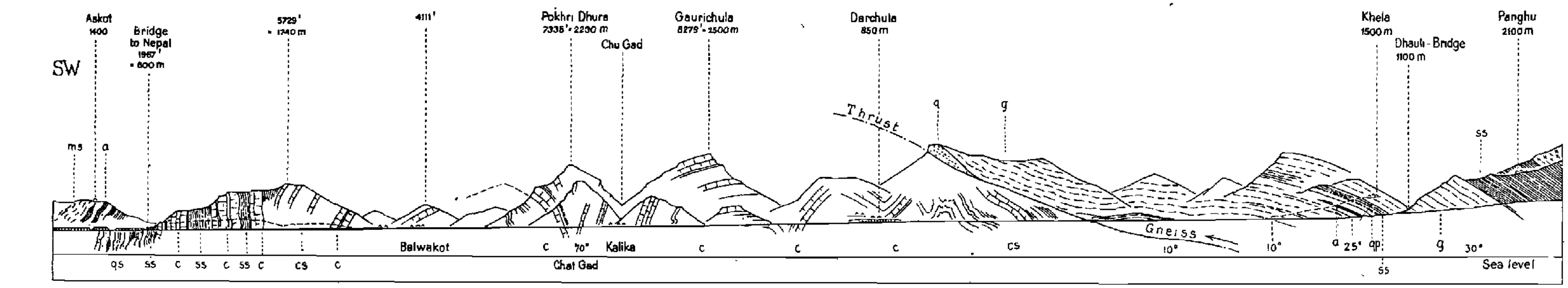
from S to N: S_1 = lower Siwalik, S_2 = upper Siwalik *(congl.)*, C = Gondwana, Carb., D = Dalings, ms = mica schists, g = gneiss, gr. = granite, L_1 = low Everest limestone, L_2 = upper Everest ls, ss = sericitic schists, P = Permian, J = Jurassic, C = Cret., E = Eocene. After the top. maps, Mallet, Garwood, Hayden, Heron, Dyhrenfurth, Wager, Auden and observations of the authors.



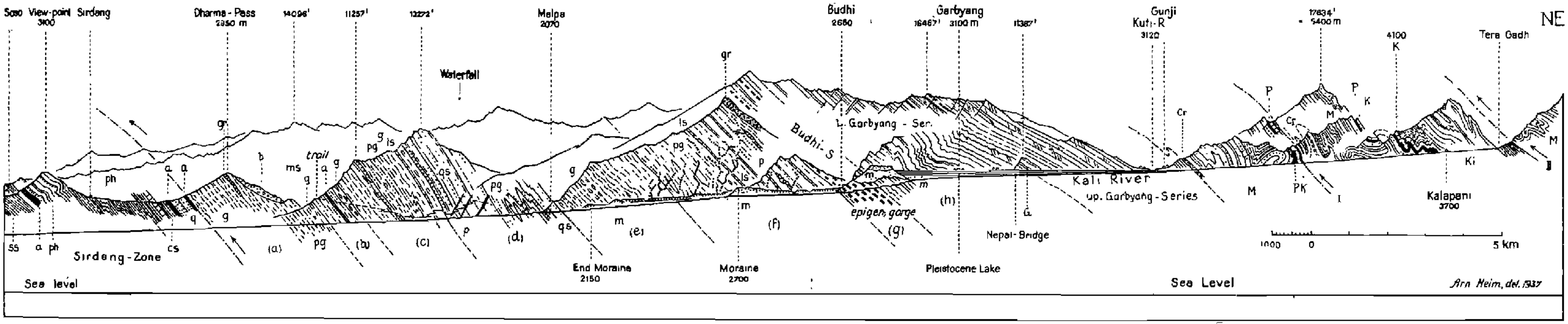
Sect. 3

3. Section Ranikhet-Dwarahat. ms = mica schists, q = quartzite, sq = sericite quartzite, g = orthogneiss, gr. = granite, qp = quartz porphyry, c = limestone, vs = variegated slate (Krol?).

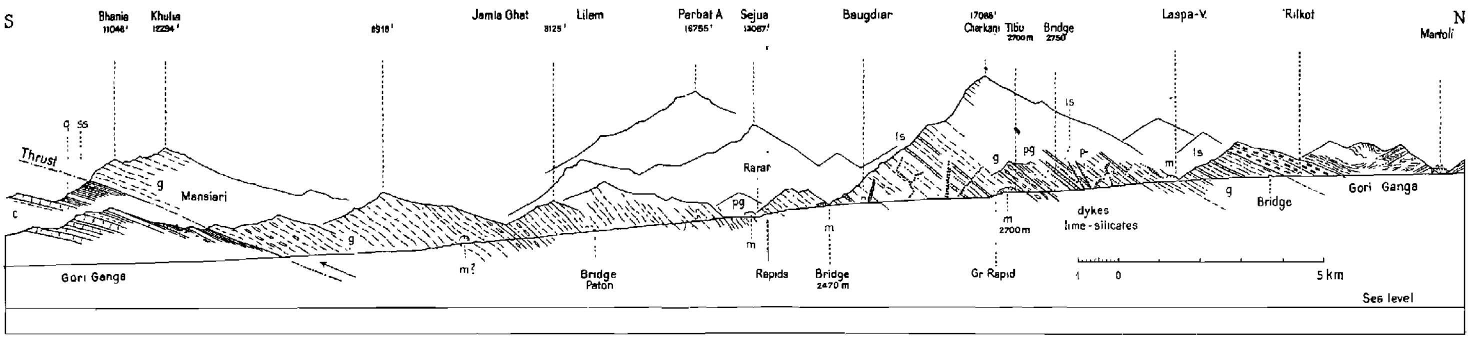
Reproducit Frets Frères S.A., Zurich



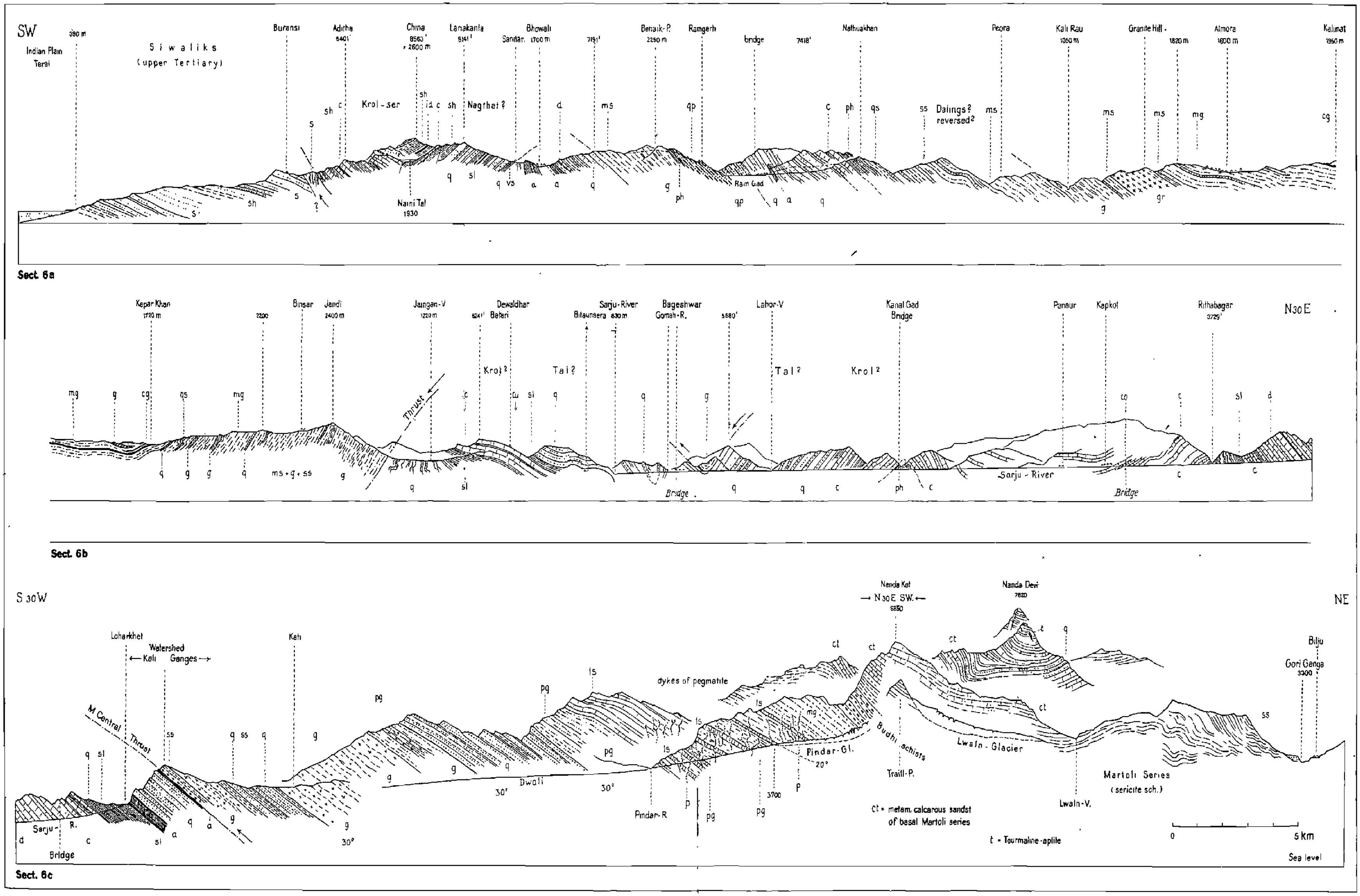
Sect. 4a



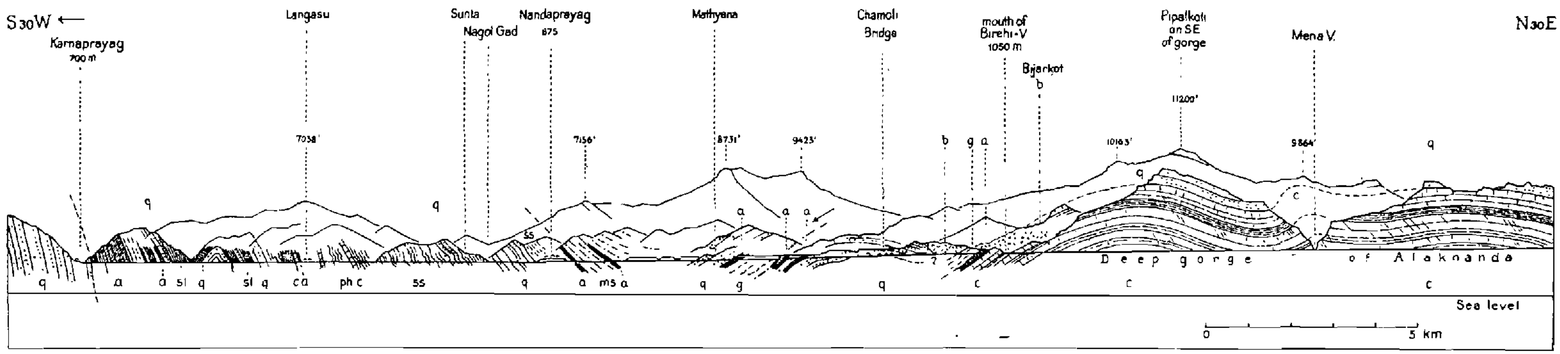
Sect. 4b



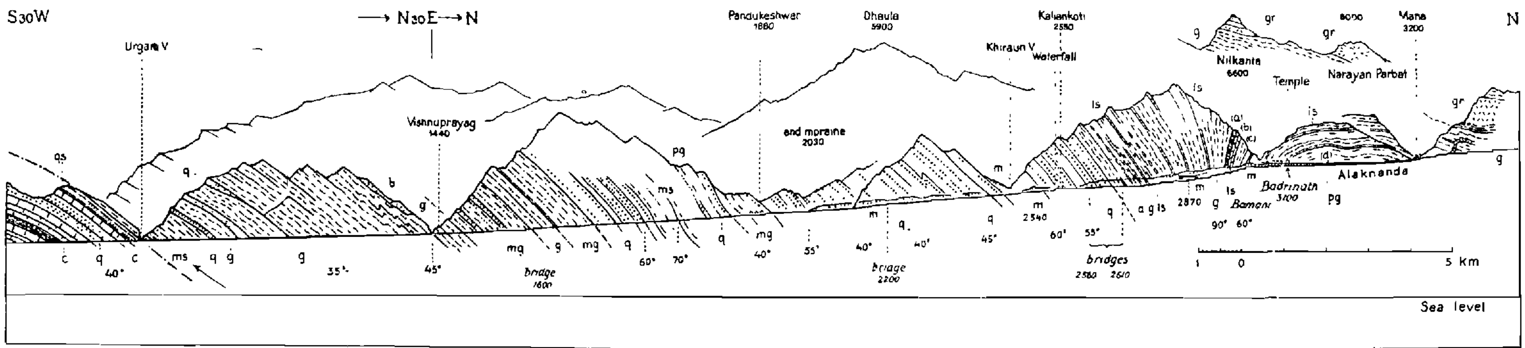
Sect. 5



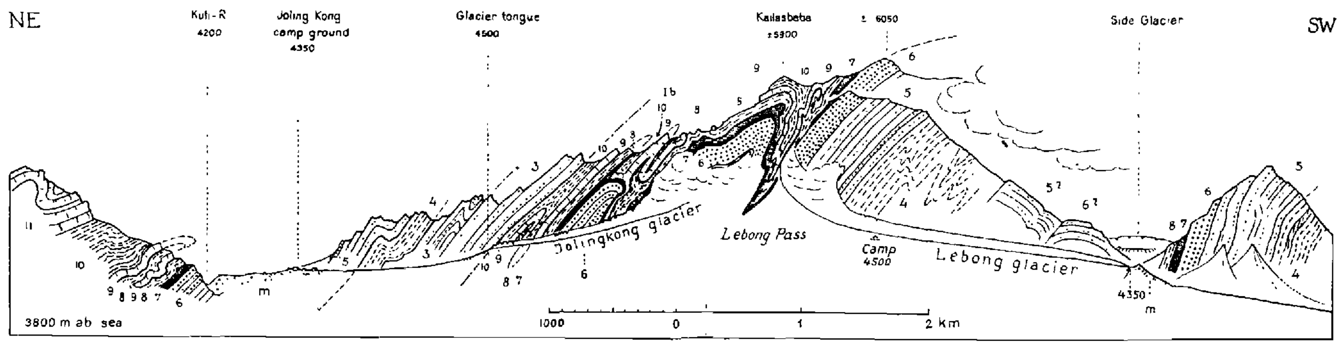
Reproduct. Pretz Frères S.A., Zurich.



Sect. 7a

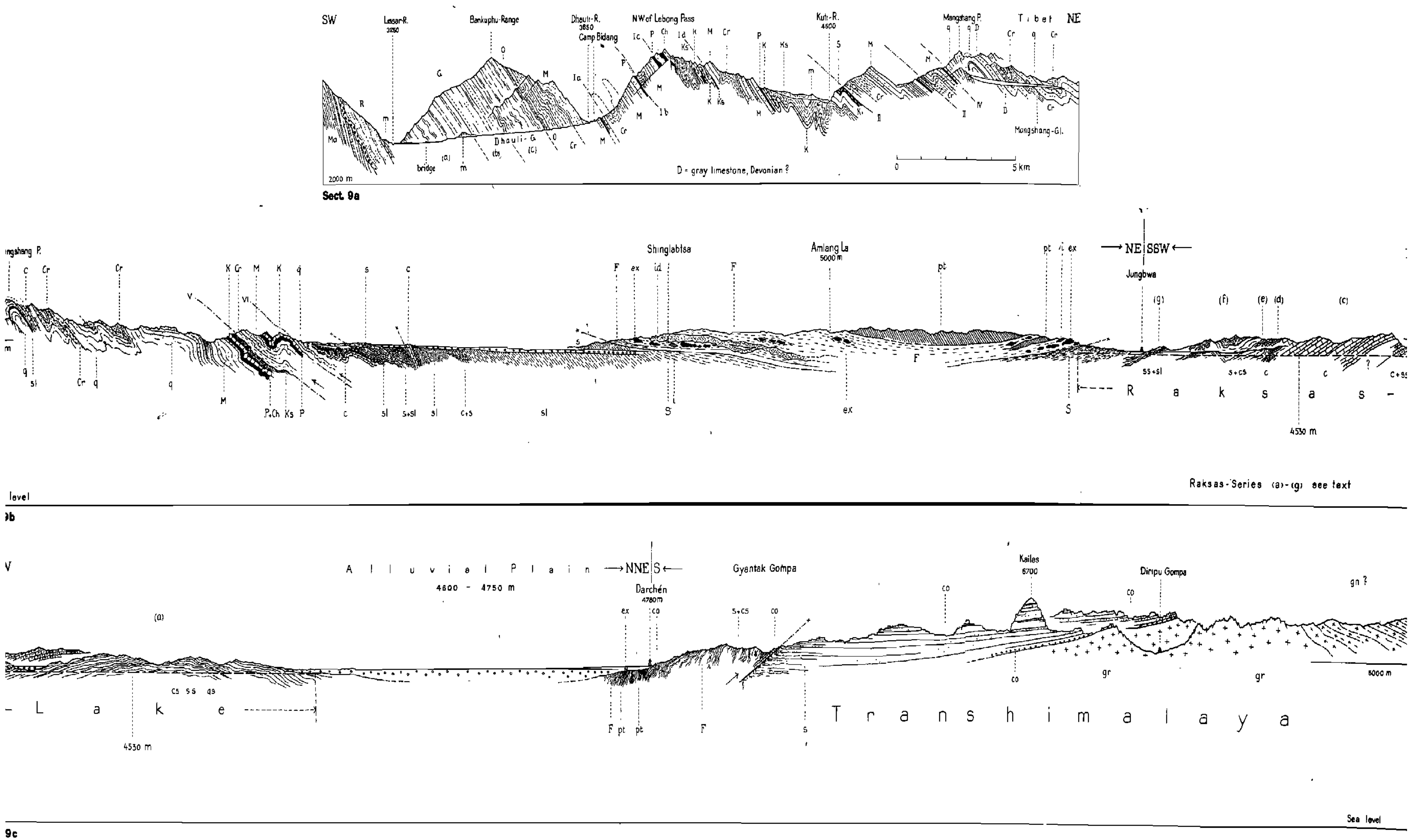


Sect. 7b



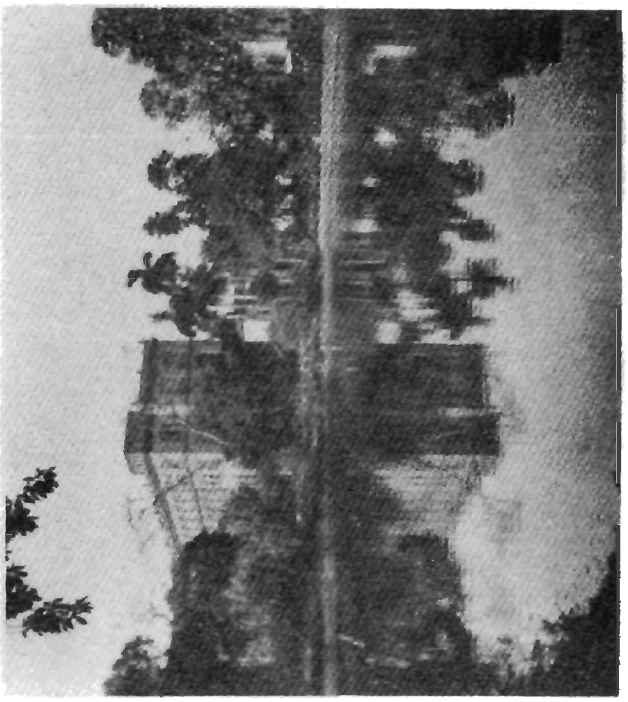
Sect. 8

Reproduct Fretz Frères S A., Zurich

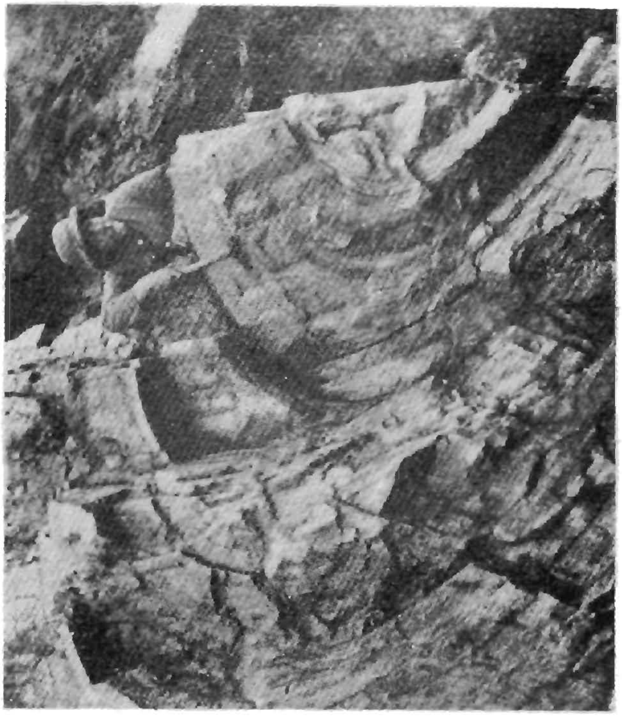

SW
Lassar-R.
3250
Bankuphu-Range
Dhauli-R.
3850
Camp Bidang
NW of Lebong Pass
Kuti-R.
4600
Mangshang P.
Tibet
NE
Dhauli-G.
bridge
Mangshang-Gl.
D = gray limestone, Devonian ?
0
5 km
2000 m
Sect. 9a
Mangshang P.
Shinglabtsa
Amlang La
5000 m
→ NE|SSW ←
Jungbwa
(g)
(f)
(e)
(d)
(c)
R a k s a s -
4530 m
Raksas-Series (a)-(g) see text
level
9b
Alluvial Plain
4600 - 4750 m
→ NNE|S ←
Darchén
4780 m
Gyantak Gompa
Kailas
6700
Diripu Gompa
gn ?
(a)
Lake
4530 m
Transhimalaya
5000 m
Sea level
9c

1 Tele-view of the Central High Range from Naini Tal (photogr. by courtesy of Kinsey Bros.) Note the backward inclination of the great scarp face of gneiss-mica schist-phyllite series above the Main Central Thrust, which *corresponds* about to the present snow line above the wooded lower ranges.

2 The Kiogars seen from *SW at* 4800 *meters.* 1 = lower; 2 = middle; 3 = upper Glumal series (Low. Cret.); 4 = red and green calcareous shale; 5 = black flysch with fucoids; b = basic igneous with S = serpentine. Compare *text Fig.* 118. Aug. 8, 1936 (H).



3 The geological Survey of India, Calcutta, home of the geology of the Himalaya (H).



4 Synclinal fold of quartzite in mica schists at Kurseong below the Darjeeling road, March 1936 (G).

5 Type of Landscape N of Almora, showing the somewhat peneplained region of thrusted mica schists (H).

6 Granite intrusions in the crystalline series. Background of Api Glacier, looking to SE (H).

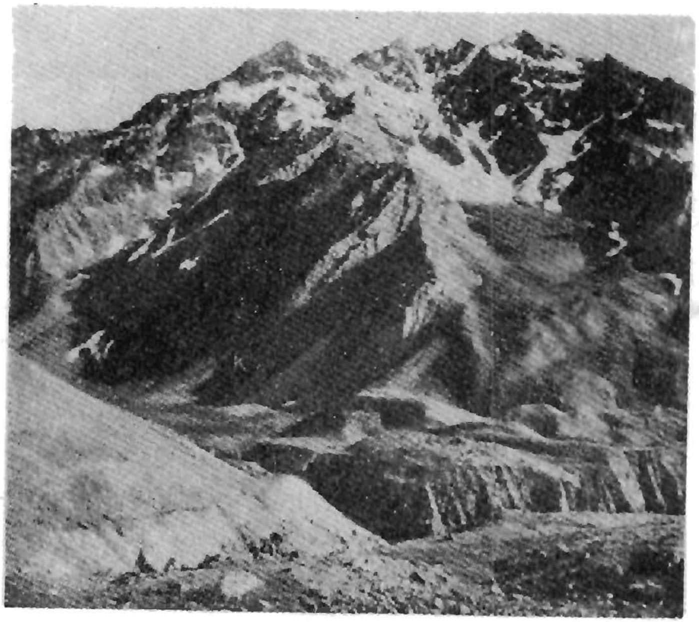
7 Fluidal folding of Darjeeling gneiss, Samsing. gn = gneiss; ap = aplitic vein; ps = psammite gneiss (H).

8 Block of Darjeeling gneiss at Samsing with: ca = calcsilicate inclusions (H).

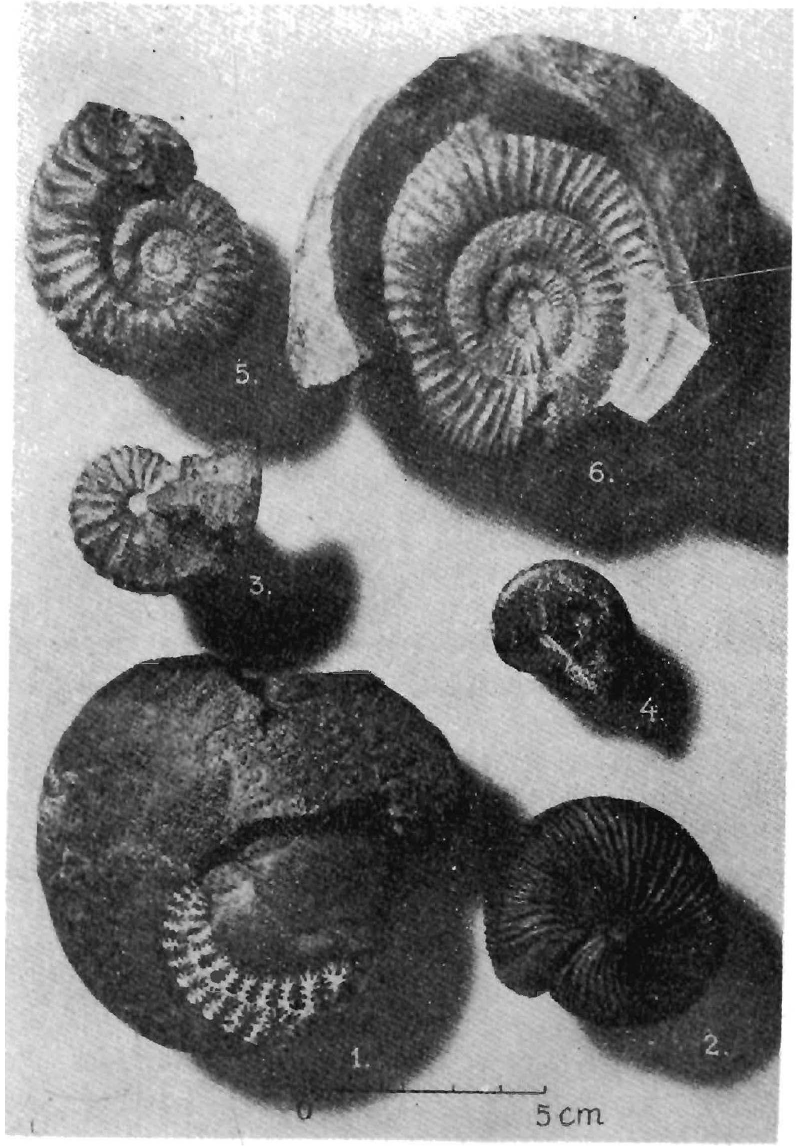
9 Garnetiferous calcsilicate (ca) in the Darjeeling gneiss. Block at Samsing (H).

10 Details of fluidal thrust-folding of the Darjeeling gneiss. Block in the Murti River, Samsing (H).

19 The fossil discovery of Norian on Tinkar Lipu, 5200 meters looking SW, May 24, 1936 (H).



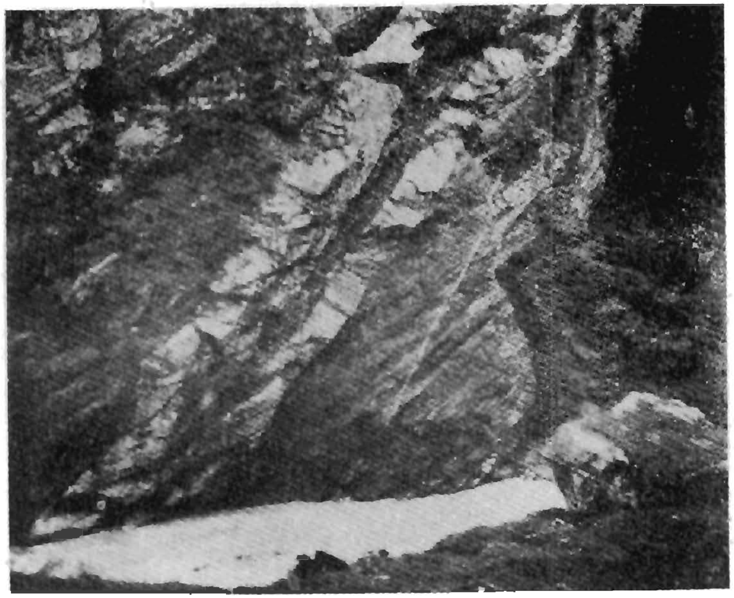
20 Lilinthi camping ground with moraine dam of recession in fore-ground at 4300 meters, looking south from Lipu Lek trail (H).



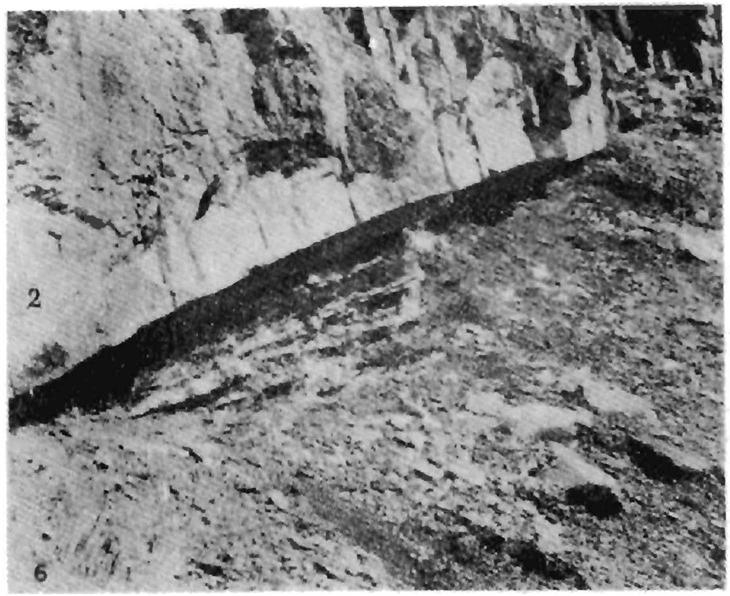
21 Types of ammonites of the Tethys-Himalaya: 1 = Cyclolobus Oldhami Waagen, upper Permian; 2 = Parajuvavites sp. nov.; 3 = Paratibetites Adolphi Mojs; 4 = Placites Sakuntala v. Mojs; 5 = Steinmannites sp. nov.; 2—5 = Norian of Tinkar Lipu; 6 = Perisphinctes cf. biplicatus Uhlig, in siliceous concretion of Spiti shale, Laptal, Portlandian.

22 The Ralam Valley looking ENE, showing recently accentuated erosion of former fan deposits. July 25, 1936 (H).

23 The thrust I b on the Shiala Glacier (Sg) looking NW. S = Silurian; b = brown; w = white quartzite; M = Muth Q.; P = Productus shale; K = Kalapani ls.; Sg = Shiala Glacier; Kg = Kundekang Gl. with its left lateral moraine = m (H).



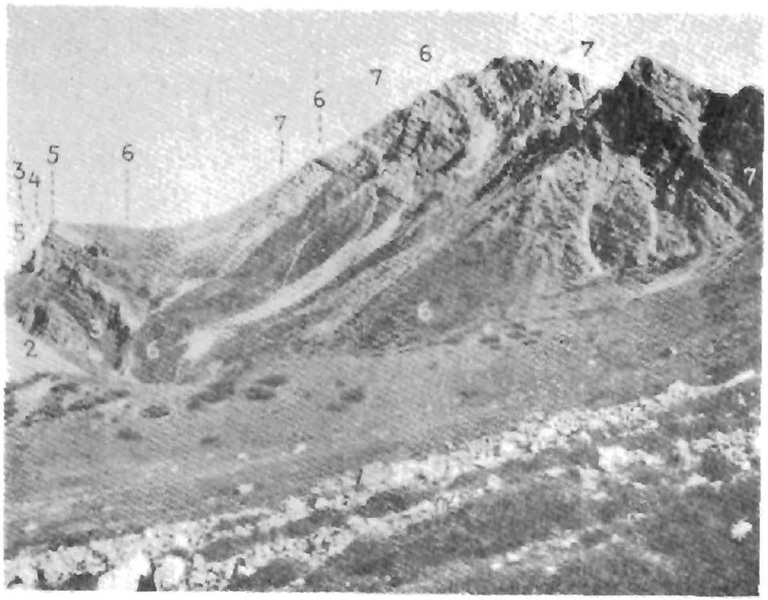
24 Dykes of Pegmatite and Aplite diagonally traversing the gneissic biotite schists of the Gori Ganga below Rilkot, looking east (H).



25 Detail of the above thrust I b on the SW side of Shiala Glacier. 2 — white Quartzite (Muth); 6 = Kuti shale (H).

26 Kuti, 3750 meters, seen from SW, showing from below 4 = low. Trias; 6 = Kuti shales; 7 = *Kioto* limestone; 8 = Spiti shales S = thrusted Paleozoic (silurian). In left background the Shangtang, 6480 meters (H).

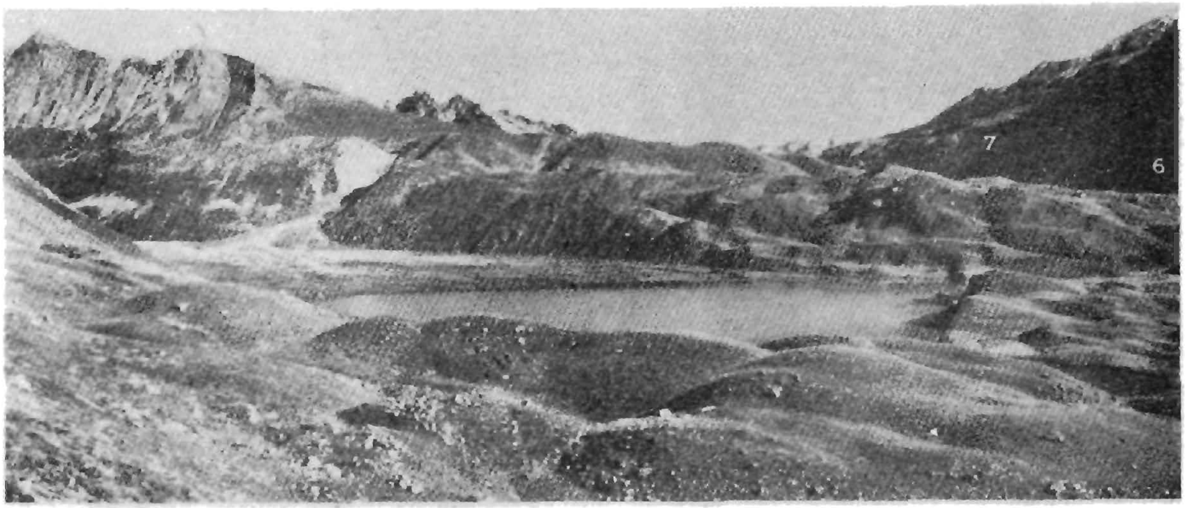
27 *Structure of Kuti, looking to SE.* In foreground the castle-hill. 1 = Silurian; 2 = Muth quartzite; 3 = Kuling shales (Perm.); 4 = Chocolate series; 5 = Kalapani ls.; 6 = Kuti shales (Norian); 7 = Kioto ls. (Rhaetic); w = wedge syncline; f = fan deposits, recent. (H).



28 *Kuti Valley W of Kuti, looking NW.* 2 = Muth Q.; 3 = Kuling sh.; 4 = Chocolate sh.; 5 = Kalapani ls.; 6 = Kuti sh.; 7 = Kioto ls. (H.)

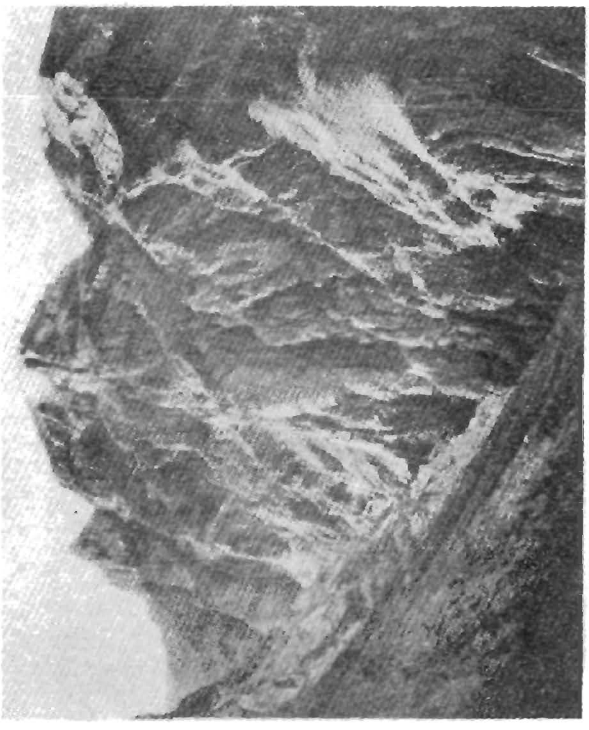
29 Structure NW of Kuti (Thumka Gad), looking NW. S = Silurian (thrust II); 7 = Kioto limestone (Rhaetic); 8 = Spiti shale. Compare Text fig. 95.

30 Shiala Pass (Gap in middle) and Tsherpedang Glacier (right). All Garbyang series except + rock on right = fossiliferous Ordovician sandstone. View from 4900 met. to SW. July 1, 1936 (H).

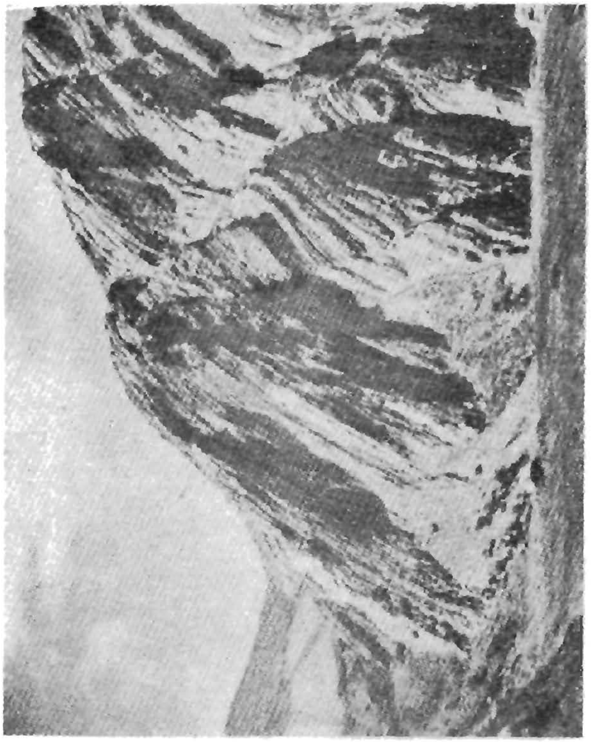


31 The moraine lake of Joling Kong, 4400 met., Kuti Valley, looking to NW. o = red Crinoid shale (low. Sil.); 1 = brown quartzites; 2 = white Muth quartzite 3 = Kuling- and Chocolate shales; 5 = Kalapani ls.; 6 = Kuti sh.; 7 = Kioto ls. July 15, 1936 (H).

32 The Milam Glacier, looking to NW. See subrecent lateral moraine on left side. Aug. 25, 1936 (H).



42 The Chidamu-Gorge across the Lahur anticline made of Kiolo limestone, looking eastward (H).

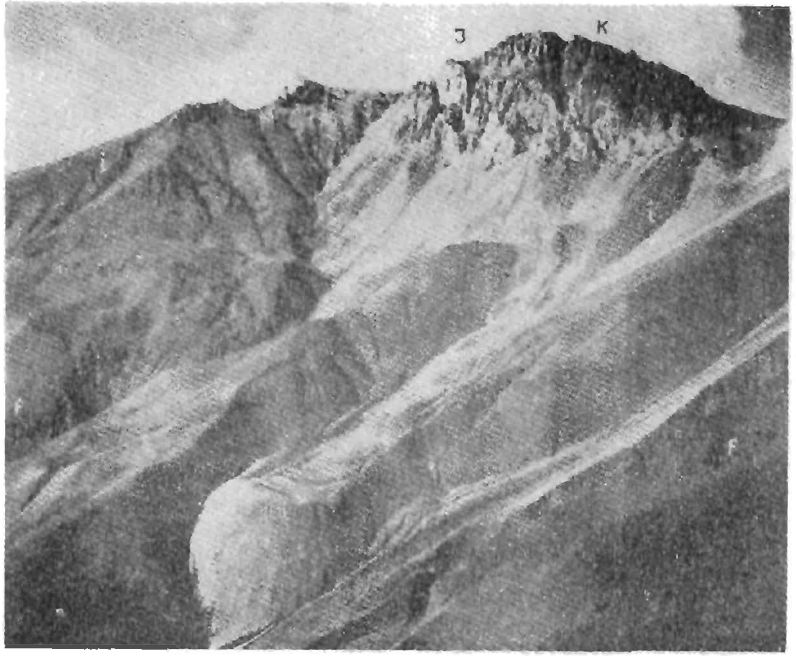


43 The lumachelle of Laptal series (Lias), Laptal, looking NNW (H).

44 Exotic Blocks 1 and 2 in basic igneous, W of point 18110', Balchdhura. Nr. 1 full of Carnic ammonites (H).

45 Balchdhura Pass (+), 5360 meters and Heights 5800 meters, looking to NW. Crest of basic igneous with exot. blocks. In foreground serpentine: × = ophicalcite (H).

46 The exotic Kiogar region from Kiogar Nr. 2 towards NE. Mainly Kiogar ls. (Dachsteinkalk); + red Jurassic of Kiogar Nr. 3, Aug. 14, 1936 (H).

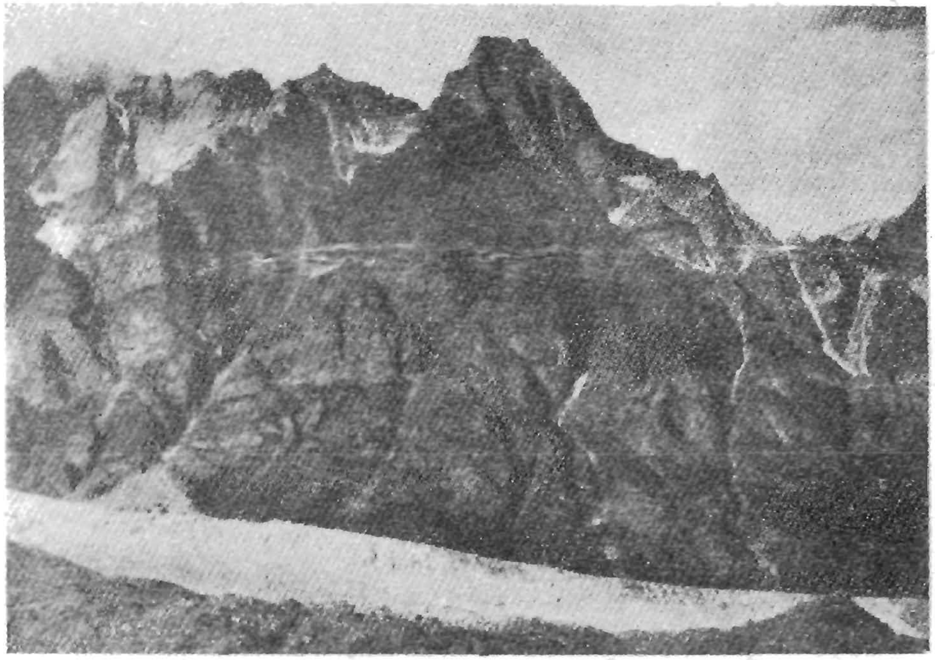


47 Solifluction on flysch of talus from Kiogar Nr. 2, chiefly of dolomitic Kiogar limestone (K). f = flysch, upper Cret.; I = basic igneous with exot. blocks; J = reddish sh. + ls., Jurassic (H).

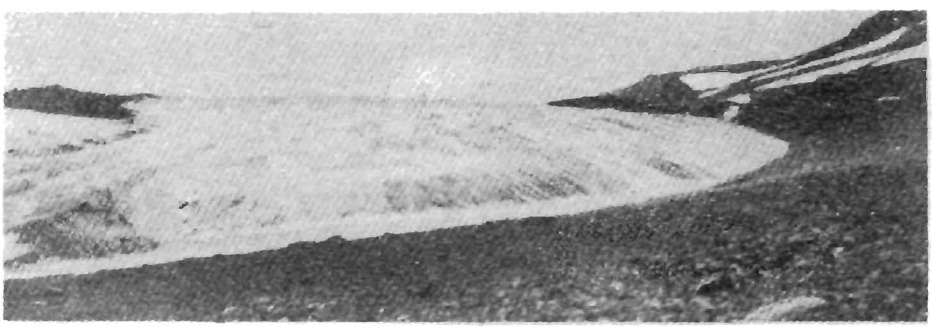
48 The flysch region south of the Kiogad, seen from Kiogar Nr. 2 at 5700 meters; g = Giumal sdst.; r = red flysch; f = black flysch; i = basic igneous sheet with exotic blocks above; + = Permian; × = Lias; ↓ Panch Chulhi 6910 meters; L = top of Lahur anticline (H).

49 The famous "Chirchun Nr. 1", 17740' from SW, showing 3 exotic blocks of Permian in and upon siliceous flysch (with radiolarians) under solifluction. + small block of "Hallstätterkalk". Right background: anticline of Kioto ls. with pleistocene gravel terrace above (H).

50 Nampa 7140 meters in middle, and Api Valley seen from Garbyang. On left background is the peak 19919' (basal Garbyang series). m = Api moraine of recession (Top at 3670—3700 meters) (H).

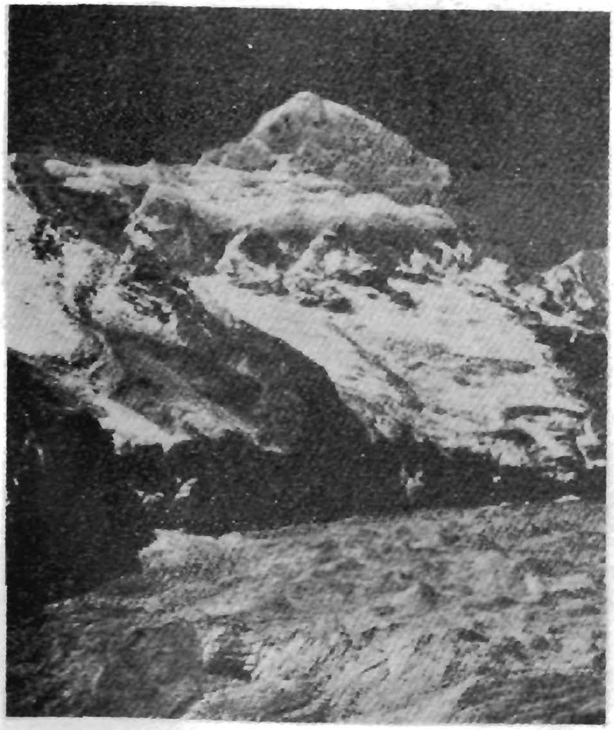


51 Crystalline series with granite injection north of Bhagat Kharak glacier. The white crest is the left subrecent lateral moraine (H).

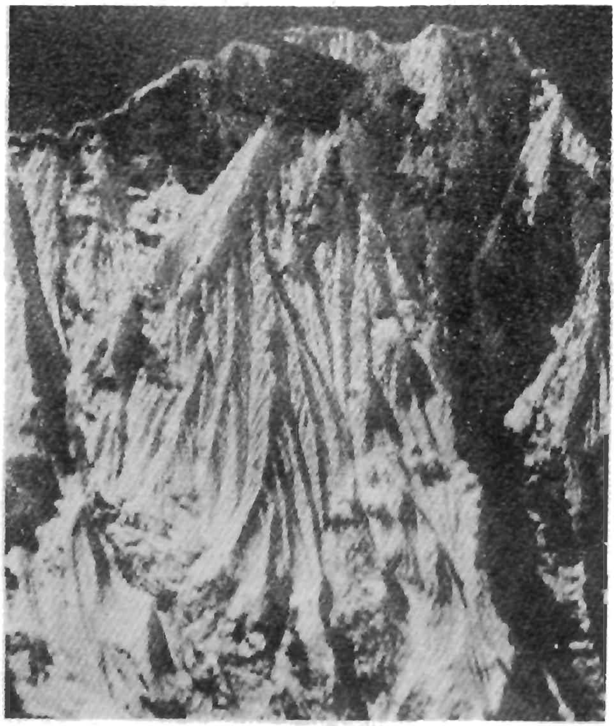


52 The end of the eastern Mangshang Glacier in Tibet at 5050—5100 meters, looking SW (H).

53 The Dhauli Valley of Garwhal. Cultivated terraces on Kuari mountain slide. In background Dunagiri 7060 meters; R = Rishi valley. The walls are of Mica schists with quartzite and gneiss (H).



54 Nilkanta 6600 meters and the source of the Ganges (Gate of Satopanth Glacier) from N (H).

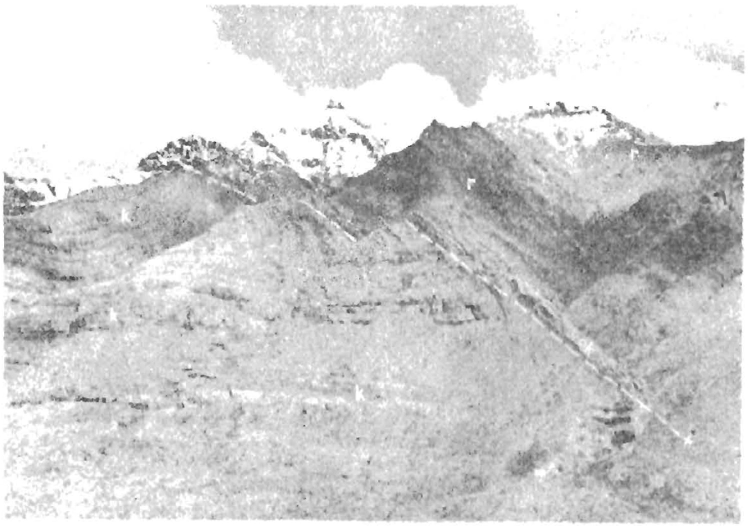


55 Saw-furrows ("Sägerillen") of ice, Satopanth-group, about 6500 meters, seen from NE (H).

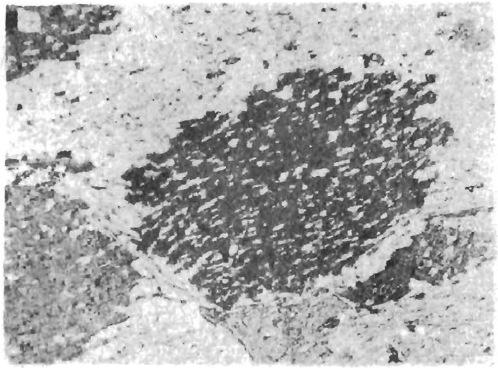
62 The Pleistocene conglomerates of the upper Shib Chu, Tibet, looking north, from the northern part of Ghatamemin. ex = exotic blocks; ch = *Chilam-Kurkur series*; p = *peridotite*; t = Transhimalayn; gr = Pleistocene conglomerate (G).

63 The Pleistocene conglomerates of the Shib Chu, Tibet, with the abandoned cave dwellings (G).

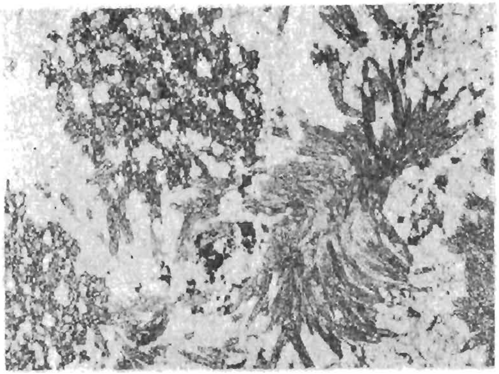
64 The exotic blocks south of Amlang-La, Tibet (G). f = flysch sandstone; ex = exotic blocks of lower Trias; c = upper Cretaceous flysch-limestone; sd = young syeno-diorite cutting the limestone unconformably.



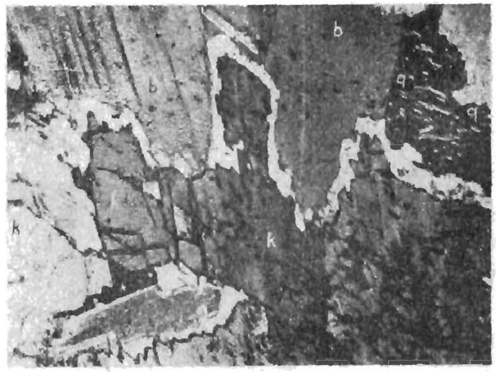
65 The counter-thrust south of the Kailas, Tibet (G), left side of valley. k = Kailas conglomerate with sandstone layers; ok = thrust Kailas conglomerate; r = red shales and sandstone (flysch); x = thrust plane.



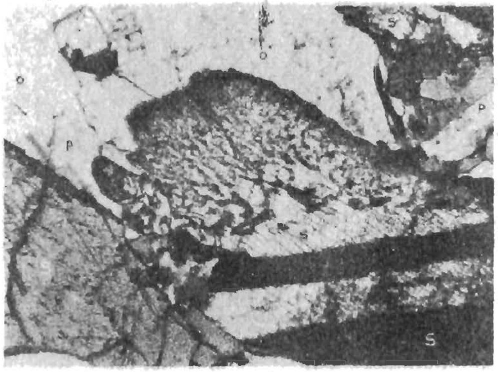
66 Sieve-like Biotite Porphyroblast from Biotite Porphyroblast schist of Budhi, zone g of Kali river. Inclusions in Biotite and Quartz. *Matrix* consisting of Quartz and Sericite. Ni , slice 128 (G). Enlargement 35 times.



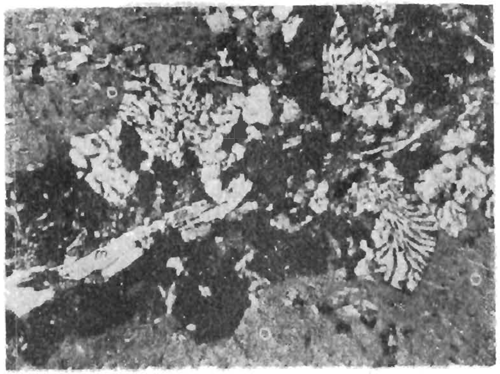
67 Actinolite sheaves and sieve-like Garnet Porphyroblasts from Garnet - Actinolite - Quartzite, Nampa Valley, Nepal. Matrix of Quartz. The dark parts are Titanite. Ni slice 122 (G). Enlargement 15 times.



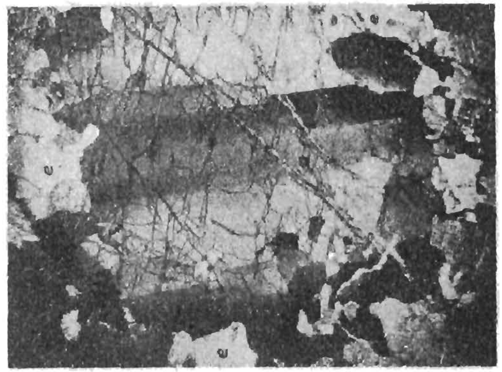
68 Reaction border of Quartz between Kyanite and Biotite, from Kyanite-Biotite schist, Api Glacier, Nepal (G) Ni × slice 118. The bright zone is Quartz; b = Biotite; q = Quartz with poikiloblastic inclusions; K = Kyanite (see petrogr. Kali-Api). Enl. 25 times (G).



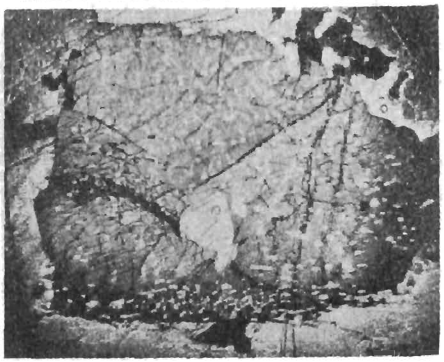
69 Myrmekitic replacement of Orthoclase by Spodumene, from Spodumene-Pegmatite. Bhagat Kharak. *Ni ×, slice* 180 (G). s = Spodumene (polysynthetic twin lamellae): o = Orthoclase; p = Plagioclase. The dark parts in the Spodumene are Quartz. Enl. 67 times.



70 Myrmekitic replacement of Orthoclase by Plagioclase along a crack in the Orthoclase. Ni × Augengneiss of Soso (G) slice 79; o = perthitic Orthoclase; m = Muscovite. *Enlargement 38 times.*

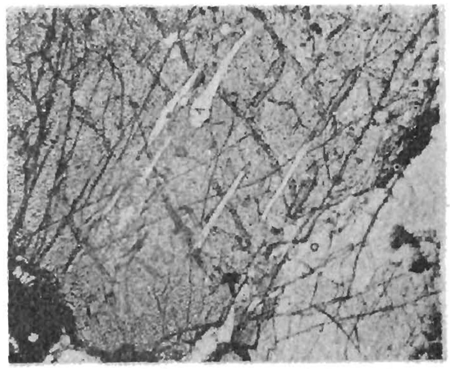


71 Olivine with stress-lamellae, from Enstatite - Peridotite, Jungbwa, Tibet (G). Ni × slice 205; e = Enstatite. Enlargement 17 times.

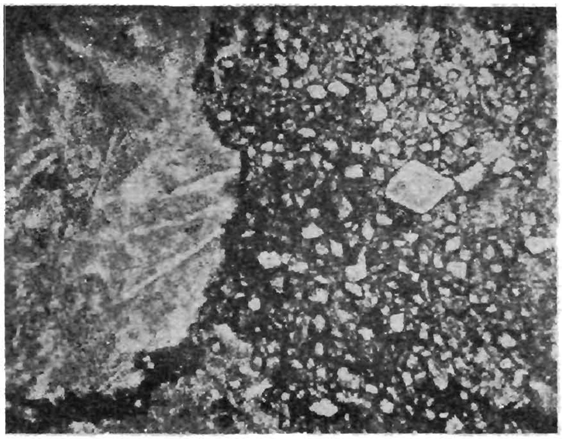


72 Enstatite with drop-like segregation of ordinary Augite, from Enstatite-Peridotite, Jungbwa, Tibet (G) Ni × slice 205. o = Olivine. The clear drops on the uniform Enstatite are ordinary Augite. Enlargement 16 times.

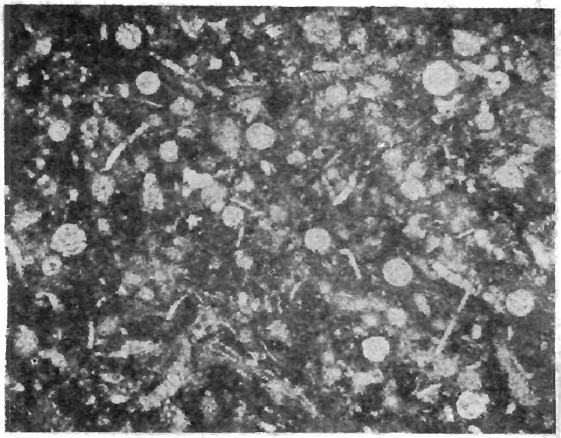
73 Enstatite with lamella-shaped segregation of ordinary Augite. *Slice about parallel* to the c-axis. From Enstatite-Peridotite, Jungbwa, Tibet (G). Ni ×, slice 202, o = Olivine. The clear scales are ordinary Augite. Enlargement 35 times.



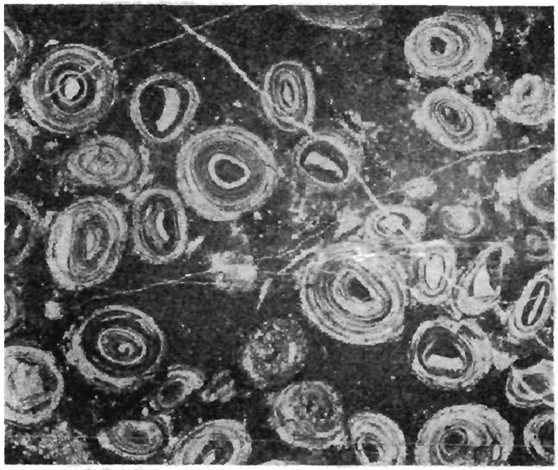
74 Enstatite with segregation of ordinary Augite, which presents two differently directed individuals 1 and 2 (G) Ni × slice 205, o = *Olivine. Enlargement 30 times.*



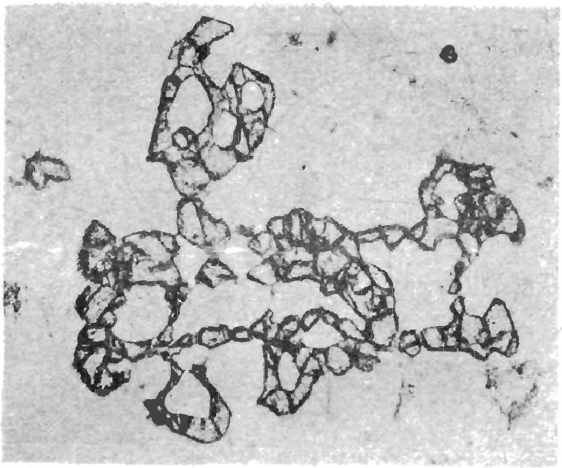
75 Kalapani limestone with ankeritic patches showing the ankeritic rhombohedrons. Tinkar Lipu, Nepal (H), ordinary light, slice 264. Enlargement 20 times.



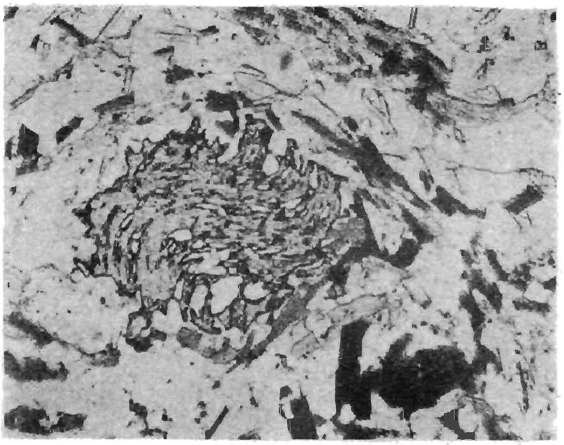
76 Cretaceous (?) siliceous limestone of Kiogar Nr. 2, with sponge spiculae and Radiolarians (H), ordinary light, slice 8. Enlargement 50 times.



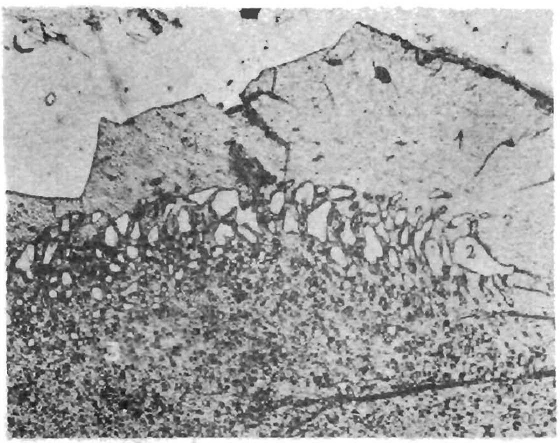
77 **Ferruginous Oolite, Callovian, from Laptal. In the dense, impure calcareous matrix are calcite ovoides with varied, partly fragmentary cores (H), slice 251. Enlargement 20 times.**



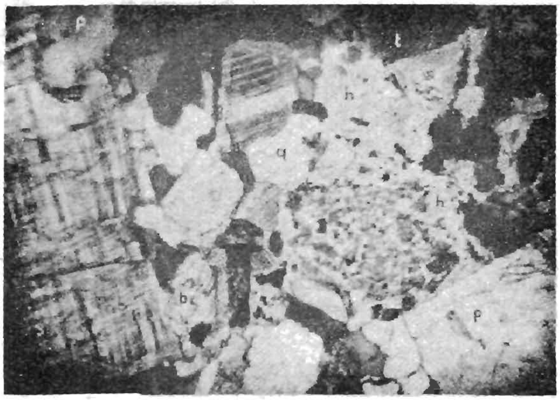
78 Reticular relic of Garnet. Sericite Quartzite east of Darjeeling (G) Ni .. *slice 18, Enlargement 65 times.*



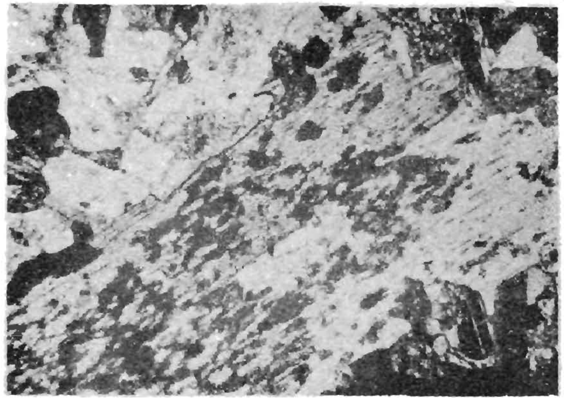
79 Twisted Garnet from Biotite-Psammite Gneiss, east of Darjeeling (G). Ni , **slice 26. On the photo**: Garnet, Biotite and Muscovite. Enlargement *40 times.*



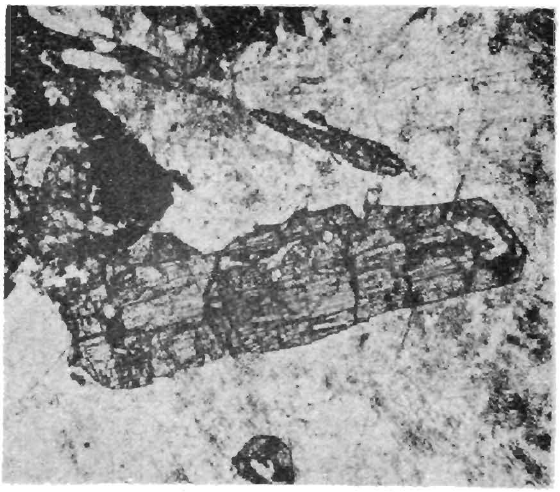
80 Large Garnet with Quartz-inclusions from Staurolite-Garnet-Biotite-Phyllite NE of Samkola, Kali Gorge (G) Ni //, slice 92. 1 = border free *of Quartz with "drops" of ore; 2 = zone of large Quartz inclusions;* 3 = central part with small Quartz inclusions and ore. Enlargement **80 times.**



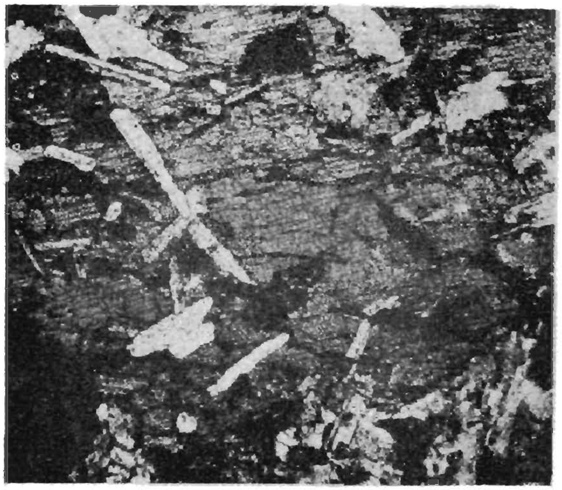
81 Hornblende — Biotite Granite, north side of Kailas, Tibet (G). Ni × slice 208, mi = Microcline; h = Hornblende with relictic Augite (dark inclusions); p = Plagioclase; b = Biotite; t = Titanite; q = Quartz. Enlargement 17 times.



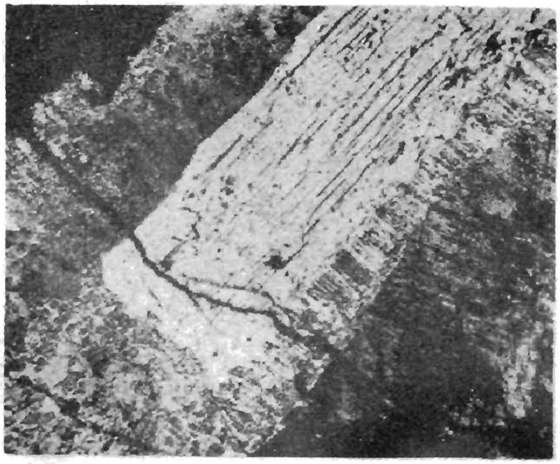
82 Hornblende with relictic Augite from Kailas granite north of Kailas, Tibet (G). Ni ×, slice 209. Hornblende forming twins; Augite recognizable as dark patches in the hornblende; Plagioclase beside the hornblende. Enlargement 35 times.



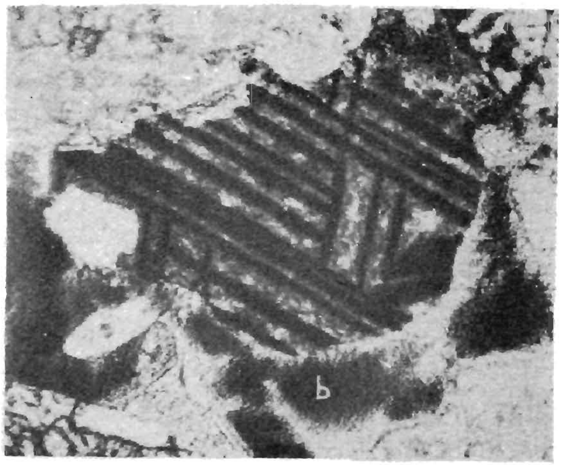
83 Pigeonite of Syeno-Diorite, Amlang-La, Tibet (G). Ni /, slice 200, Pigeonite inside of Perthite. Enlargement 35 times.



84 Pigeonite with idiomorphic Andesine laths, from Syeno-Diorite, Amlang-La. The Pigeonite is dark, the Andesine clear (G). Ni ×, slice 198. Enlargement 50 times.



85 Andesine with border of Perthite, from Syeno-Diorite, Amlang-La, Tibet (G). Ni ×, slice 200. Enlargement 53 times.



86 Ilmenite-lamellae from altered Biotite, Syeno-Diorite, Amlang-La, Tibet (G). Ni /, slice 198, black = Ilmenite; b = Biotite; between the black lamellae is Leucoxene. Enlargement 80 times.